Joseph Le Conte

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WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY.

E. A. BIRGE, Director. C. R. VAN HISE, Consulting Geologist.

BULLETIN NO. IV. ECONOMIC SERIES NO. 2.

ON THE

Building and Ornamental Stones

OF

WISCONSIN.

BY

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TABLE OF CONTENTS.

PART I.

DEMAND, USES, AND PROPERTIES OF BUILDING AND ORNAMENTAL STONES.

PART II.

GEOLOGICAL HISTORY OF WISCONSIN AND DESCRIPTION OF AREAS AND QUARRIES.

CHAPTER II.—THE IGNEOUS AND METAMORPHIC ROCKS—cont.

Section I—The Igneous Rocks—cont. PAGE

CHAPTER IV.—SANDSTONE—cont.

CHAPTER VI.—LIMESTONE—cont.

CHAPTER VII.—AREAS FROM WHICH SUITABLE STONE FOR DIFFERENT USES MAY BE OBTAINED—cont.

PAGE

PART III.

ILLUSTRATIONS.

FIGURE.

SAMPLES OF WISCONSIN BUILDING AND ORNAMENTAL STONES IN THE LABORATORY OF THE SURVEY.

These samples are about 8 inches by 8 inches by 8 inches in size, and have variously dressed faces. The granite and rhyolite, as well as two of the limestone samples, have one or more polished faces. In the following list, only the location of the quarry is given.

GRANITE.

Montello Granite Co., Montello Wis. Red granite.

The L. S. Cohn Granite Co., Granite Heights, Wis. Wausau red granite.

The L. S. Cohn Granite Co., Granite Heights, Wis., Wausau gray granite.

The New Hill O'Fair Granite Co. (Olson & Magnesun), Granite Heights, Wis. Wausau red granite.

The Granite Heights Granite Co., Granite Heights, Wis. Wausau red granite.

The Amberg Granite Co., Amberg, Wis. Athelstane gray granite.

The Pike River Granite Co., Amberg, Wis. Fine-grained gray granite.

The Waupaca Granite Co., Waupaca, Wis. Gray granite.

The Waupaca Granite Co., Waupaca, Wis. Red granite.

French Granite Co., High Bridge, Wis. Grayish-red granite.

O. J. Jenk's Quarry, Irma, Wis. Pink granite.

The Berlin Granite Co., 9 miles northwest of Berlin. Red granite.

J H. Leuthold's quarry, Granite City, Wis. Red granite.

RHYOLITE.

The E. J. Nelson Granite Co., Berlin, Wis. Dark rhyolite.

The Green Lake Granite Co., Utley, Wis. Dark rhyolite.

SANDSTONE.

Miller Bros. & Johnson, Port Wing, Wis. Brown sandstone.

Miller Bros. & Johnson, Port Wing, Wis. Brown "raindrop" sandstone.

Babcock & Smith, Houghton, Wis. Brown sandstone.

Bass Island quarry (Geo. P. Lee), Bass Island, Wis. Two samples of brown sandstone.

Ashland Brownstone Co., Presque Isle, Wis. Three samples of brown sandstone.

The Prentice Brownstone Co., Houghton, Wis. Two samples of br sandstone.

R. D. Pike, Pike, Wis. Brown sandstone.

Duluth Brownstone Co., across river from Fond du Lac, Minnes Brown sandstone.

E. F. & B. Shirrill, Argyle, Wis. Brown sandstone.

E. A. Grover, La Valle, Wis. Red sandstone.

C. A. Bender, Grand Rapids, Wis. Two samples of buff sandston

Dunnville Stone Quarry, Dunnville, Wis. Buff sandstone.

LIMESTONE.

Story Bros., Wauwatosa, Wis. Three samples of gray limestone.

Genesee Quarry Co., Genesee, Wis. Two samples of light buff li stone.

Frank Bauer, Knowles, Wis. Light buff limestone.

W. A. Aldrich, Burlington, Wis. Pink limestone.

Bridgeport Stone Quarry, Bridgeport, Wis. Buff limestone.

The Marblehead Lime and Stone Co., Marblehead, Wis. Gray lime stone.

The Menominee Falls Quarry Co., Lannon, Wis. Gray limestone.

The Washington Stone Co., Sturgeon Bay, Wis. Blue limestone.

The Laurie Stone Co., Sturgeon Bay, Wis. Buff limestone.

The Gillen Stone Co., Duck Creek, Wis. Blue limestone.

W. H. Jones, Neenah, Wis. Blue limestone.

Phillip Abendschein, Neenah, Wis. Blue limestone.

William Samp, Beloit, Wis. Buff limestone.

The Prentice Brownstone Co., Houghton, Wis. Two samples of brown sandstone.

R. D. Pike, Pike, Wis. Brown sandstone.

Duluth Brownstone Co., across river from Fond du Lac, Minnesota. Brown sandstone.

E. F. & B. Shirrill, Argyle, Wis. Brown sandstone.

E. A. Grover, La Valle, Wis. Red sandstone.

C. A. Bender, Grand Rapids, Wis. Two samples of buff sandstone.

Dunnville Stone Quarry, Dunnville, Wis. Buff sandstone.

LIMESTONE.

Story Bros., Wauwatosa, Wis. Three samples of gray limestone.

Genesee Quarry Co., Genesee, Wis. Two samples of light buff limestone.

Frank Bauer, Knowles, Wis. Light buff limestone.

W. A. Aldrich, Burlington, Wis. Pink limestone.

Bridgeport Stone Quarry, Bridgeport, Wis. Buff limestone.

The Marblehead Lime and Stone Co., Marblehead, Wis. Gray limestone.

The Menominee Falls Quarry Co., Lannon, Wis. Gray limestone.

The Washington Stone Co., Sturgeon Bay, Wis. Blue limestone.

The Laurie Stone Co., Sturgeon Bay, Wis. Buff limestone.

The Gillen Stone Co., Duck Creek, Wis. Blue limestone.

W. H. Jones, Neenah, Wis. Blue limestone.

Phillip Abendschein, Neenah, Wis. Blue limestone.

William Samp, Beloit, Wis. Buff limestone.

INTRODUCTION.

To understand the characteristics of building and ornamental stones, one must be familiar with the composition, manner of formation, and occurrence of the common minerals and rocks. It is frequently necessary in discussing the chemical, mineralogical, and physical qualities of stones to use terms with which the general public is not familiar. In view of these facts, and for the benefit of those who have little or no knowledge of the composition and kinds of minerals and rocks, or of the common rock structures, it has been thought best to include an appendix on these subjects.

The first part of the report is devoted to a discussion of the demands and uses of stone, the important considerations in the selection of stone, and the methods by which the value of stones for different purposes may be estimated. The second part embraces a full discussion of the building and ornamental stones of Wisconsin, their manner of occurrence, color, composition, adaptability, strength, and durability.

An attempt has been made to give our readers an idea of the color and texture of the more important kinds of granite and brownstone now quarried in the state, by the insertion of colored lithographs, which accompany the description of the granite and brownstone from the different quarries. These lithographs are very accurate reproductions of the polished faces of the granite and the sawed faces of the brownstones. They should prove valuable to architects and builders in selecting stone, as well as in showing people in general the variety and exceptional beauty of the building and ornamental stones of Wisconsin. It is unfortuante that the gray and light buff colors of the limestones are such that they cannot be satisfactorily repro-

duced, for which reason they have been omitted from among the lithographs.

Half-tone illustrations of a few of the more important buildings and monuments constructed out of Wisconsin stone have been inserted in various parts of the report. These are intended to convey to the reader, in a limited way, the extent to which the Wisconsin stone has been used, and the pleasing architectural effects produced thereby.

Several plates in the back part of the report illustrate the results of a number of laboratory tests, and it is thought that they will prove of service in showing the manner in which the different kinds of stone are affected when subjected either to more than their ultimate strength, or to extremely high temperatures. Accompanying these plates is a series of photographs of thin sections of different kinds of stone as seen through the microscope. Since the strength and durability of a rock largely depends upon the shape of the individual grains, and the manner in which they are united to their neighbors, attention should be given to these facts.

The accompanying general and sketch maps give a general idea of the distribution of the different kinds of rock and the location of the more important quarries in the state. The dots which indicate the location of the quarríes, represent in many instances several quarries, separated, perhaps, one or more miles from each other. Only those quarries which have been operated within the last few years, and those which give indications of possessing stone suitable for building or ornamental purposes have been indicated on the maps. It is very probable that quarries have been omitted which should have been included, but every available means was exhausted in an attempt to locate all the quarries which were in operation at the time that the investigation was in progress. In some cases, omissions may be due to the failure of the owner or operator to respond to repeated solicitations for information concerning the condition of his quarry.

Those quarries which are engaged exclusively in the manufacture of quicklime have been given very little attention in the

following report, it being the purpose to treat, primarily, of the building and ornamental products of the quarries.

While preparing this report the author collected dressed samples of stone from about fifty of the more important quarries. These samples are in the laboratory of the Survey, and may be seen by any one interested in the display. A list of the samples, and the quarries from which they are taken is given in the latter part of this volume.

The meager conception which the people have of the importance of the stone industry in this state is very evident to one who has witnessed the surprise manifested by those who see, for the first time, the many varieties of granite, sandstone, and limestone, represented by the above collection of samples. Yet the industry in this state is only beginning to be developed. The brown sandstone of the Lake Superior region is used quite largely in some parts of the country, and the indications point to a revival of interest after the depression of the last few years. The granite from many of the quarries of the state has an enviable reputation among granite workers of this and neighboring states. The home market is consuming each year more of the home product, and eventually, when prices become more nearly uniform, the granites of the eastern states and foreign countries will be unable to find any considerable market in Wisconsin. There is certainly a bright outlook for the granite industry in the future.

The limestone is not the least important stone now quarried in this state. Its adaptability to a great variety of uses, and the great number of quarries in the southern and eastern parts of the state bespeak for it an importance second to neither granite nor sandstone. It is one of the largest sources of stone quarried for local consumption, as well as an important source of stone for exportation. Not only does it supply building stone, but it is also used very largely in the manufacture of quicklime and materials for road construction.

It is to be regretted that on account of the limited time allotted for the preparation of this report, the author has been obliged to omit certain features, which would have been inter-

esting and valuable. The author intends, during the coming season, to extend the experiments on strength and durability, which were begun during the preparation of this report, in the hope of adding to the information already obtained along these lines.

In the preparation of this report, the author has had the valuable assistance of the Director of the Survey, Professor E. A. Birge, and the Consulting Geologist, Professor C. R. Van Hise, under whose careful guidance the work has reached completion. The excellent colored drawings of the granite and brownstone, reproduced in the colored lithographs, were made by Miss F. K. Denniston. The chemical analyses were made by Professor W. W. Daniells. The Survey is indebted to the University of Wisconsin for the use of the laboratories and apparatus employed in performing the physical tests. We are also indebted to Purdue University, of La Fayette, Indiana, for extending to the Survey, through Professors Goss and Hatt, the courtesies of their testing laboratory. Thanks are also due Professor N. O. Whitney, of the University of Wisconsin, for reading critically the chapter on physical tests. Messrs. C. A. Rudquist, of Ashland, and J. B. Manwaring, Jr., of Superior, assisted in gathering the historical data of the Lake Superior brownstone industry. The brief geological history of Wisconsin given in Part I., Chapter I., is based largely upon the work of the former Geological Survey which is embodied in the four volumes of the "Geology of Wisconsin." A large part of the success of this report is due to the co-operation of the quarry owners and operators throughout the state, and the willingness with which they responded to the requests for samples and information concerning the quarrying industry.

E. R. Buckley.

PART I.

Demand, Uses, and Properties of Building and Ornamental Stones.

BROWN SANDSTONE.

As it occurs along the shore of Lake Superior.

THE BUILDING AND ORNAMENTAL STONES OF WISCONSIN.

CHAPTER I.

DEMAND AND USES.

BUILDINGS.

There is probably no better indication of the civilization of a country than that exhibited by its architecture. As a people, we have not yet passed the stage in which first cost is the controlling factor in the purchase of materials for construction. This is true not only in the matter of selecting the kind of material, but also in selecting the grade. When the idea of stability enters into the factor of utility; when men build homes and places of business, not for a life-time, but for centuries of use; when our conception of beauty becomes modified by the element of durability, then the development of our stone industry will have reached a permanent basis. It is true that in the case of public buildings there has been an attempt at permanence. The present tendency, from the state house to the district school, is to discard the wooden for the brick or stone building. But too often the stately or monumental character of a public building has to be sacrificed on account of limited or insufficient appropriations; but more to be regretted is the fact that if the appropriation is too limited, durability will be sacrificed to pretentiousness.

The competition between brick, terra cotta, iron, and stone has been very sharp, and only where the builder has insisted on permanence and durability as the first considerations in the se-

lection of a material for construction, has stone been used. Often, in these instances, the contractor has selected an inferior grade in order to keep the cost nearer to that of similar structures built of wood or brick. But, in general, in spite of the decrease in the price of brick and lumber, the demand for stone has been on the increase. In large cities the demand is for fire proof buildings, and in place of the rickety wooden structures of a few years ago, magnificent brick and stone buildings are being constructed.

Wherever, in the place of a wooden building, a brick is being erected, it generally creates an additional demand for stone for trimmings, in the shape of sills, steps, caps, etc. The principal competition which stone has in this field is terra cotta, which is now being used quite extensively for some of these purposes. Stone is also used very largely for the fronts to city residences, which are mainly constructed out of brick. Many rural stores, with brick fronts, have their side and back walls built out of rough stone.

In the case of both the city residence and the country store the elements of cheapness and beauty largely control the use. In the rural districts, where stone is used for the side and back walls, it is generally of an inferior quality, unsuited to dressing. The brick which is used may be a little more expensive than this stone, but it gives the building a neater and more attractive appearance. In certain instances the stone, used in the side and back walls, is admirably suited to dressed work for building fronts, but on account of the expense of properly dressing it, brick is used. In the case of the large city, where the buildings are all brick with the exception of the fronts, there is exhibited the tendency to "show." In order to give the building as good an appearance as thousands of others wholly constructed out of stone, many of the less imposing have simply their fronts built of stone, while the side and back walls are built of brick. In some instances the fronts may be merely veneered with stone, the body of the wall being built out of brick.

Not only has the ingenuity of man been directed toward simulating solid masonry by veneering, but attention has also

been directed to the artificial production of stone, or the production of materials which resemble stone. Iron and terra cotta have been used to simulate natural stone. But all attempts to produce in a few weeks, that which it has taken nature centuries to produce, have thus far been futile. When new, terra cotta and iron have a very satisfactory, and often pleasing appearance. Nevertheless men everywhere prefer to use the natural stone, although often obliged to use the artificial products on account of the difference in the original cost.

In so far as these artificial products have found a market in the construction of buildings, they have encroached upon the stone industry. But in spite of all the encroachments of artificial products, there is, today, a use for almost every stone that is quarried. It frequently happens that the cost of transportation or labor prevents its use, and it also happens that the accessibility of a stone sometimes forces its use in places where it ought not to be used. But these are the accidents of nature. The greatest mistakes are made in attempting to use inferior stone, when a better quality is as easily obtainable.

A building may be almost entirely constructed out of stone. The walls, foundations, sills, steps, roof, chimney, floors, and wainscoting may be built of stone. A building is seldom thus completely constructed out of stone. Buildings are more frequently constructed in which no stone at all is used. Brick is often substituted for stone in the foundation as well as in the walls, and where both brick and stone are scarce, wood is frequently used. One often finds a building in which the cellar walls, underpinning, and everything are built out of blocks of wood. In all these instances the element of cost is the controlling factor. Most people prefer to build their house out of wood, foundation and superstructure, and have it paid for, rather than build it out of brick and stone and have it mortgaged. In the case of business places in a newly developed country the idea is large profits on small investments, and in accordance with this, one finds that rapid construction from cheap materials predominates. This gives rise to a mushroom growth of wooden structures, and only as the "boom" subsides

and business becomes settled are the temporary structures replaced by those of a more permanent character.

Many parts of Wisconsin have not yet entirely passed through this stage of rapid development, and time alone can bring about the needed changes in the methods of construction. As our civilization becomes more permanent, the demand for durable material for constructional purposes will increase. Finally, every public building will be constructed out of stone, every city of reasonable size will have a depot constructed of stone, and private residences built of stone will dot every thoroughfare.

MONUMENTS.

The cemeteries of our land contain thousands of monuments. Every lot has its mausoleum or headstone, and each year thousands are being added. The demand is constantly increasing, and each year the call is for a more durable material. Monuments furnish one of the most permanent records of the history of a people. It is said that under ordinary circumstances, the newspaper of today will crumble away in a century. If our Republic should be destroyed and buried in the dust, the records inscribed on the monuments of today would furnish but a very meager history of a great people.

For monumental purposes the "reputation" of a stone influences very largely the extent of its use. Likewise, the extent to which a stone is used, is often one of the largest sources of its reputation. The Scotchman does not always know a good monumental stone from a poor one, but if he is told that the granite he contemplates purchasing, came from Scotland, it is sufficient evidence to him, of its durability. In like manner the granites from Massachusetts, Vermont, and Maine, by their past extensive use, have won a reputation which gives them a prestige in the market. The New Englander, like the Scotchman, feels that any rock from his native hills is certainly worthy of any praise that can be bestowed upon it, and he contents himself with a knowledge of the place where it was quarried.

The granites and marbles of the old world have long held a high place in the estimation of our people, and it is not strange

that the stone used in some of the best monuments of our republic has been transported, at great cost, from Scotland, Scandinavia, and other European countries. This has been done, not because the granites of Wisconsin are inferior to those of the old world, but because the Scotchman loves the memory of his native land, and every rock that comes from its moors and crags is dear to him. If he cannot be carried back and laid to rest in the country which gave him birth, friends will bring a column of granite from his native country, to mark his last resting place in the land of his adoption. But as the ties which bind the adopted son or daughter to their fatherland are lost in love for their new home and country, our people will be content to have their grave marked by granite hewn from the hills of their adopted country.

The tariff has had a decided influence upon the importation of foreign granite and marble, and today the duty is so high, that foreign stone is being rapidly driven from the market. The rapid increase in the demand for granite monuments has been accompanied by a corresponding decrease in the demand for marble. The superiority of granite over marble, for monumental purposes, is no longer questioned, in consequence of which marble is now sold mainly in the rural districts. But even in the country churchyards, an occasional granite column is now erected, where a few years ago all was marble. In a climate such as ours, the lettering on the marble slabs soon becomes illegible, and it often takes but a few years to remove all signs of the original polish. The glistening white of the marble is far less pleasing to the eye than the varied color of granite. Not many years hence marble monuments will be something of the past, and in their place will be raised columns of massive granite. No more beautiful granite for monumental purposes can be found anywhere, than that which is quarried in Wisconsin. The brilliant and subdued red colored granites are unsurpassed in beauty, by any which are imported from foreign countries or the eastern states. The dark colored rhyolites and gray granites are equal in every respect to similar varieties quarried elsewhere.

ROAD MAKING.

The era of road making has scarcely begun in this country. In the cities, to be sure, many of the streets are paved, but the roads in the country, and in the towns and villages have scarcely been given a thought. Especially is this applicable to Wisconsin, where farmers haul but half loads on account of the depth of the sand or thickness of the mud. It is true that the roads are "worked" but the work has to be done over nearly every season, and half of the time the road is barely passable. Progress in other directions is making a demand on the people for better highways and the movement is slowly in that direction.

In road making there are two somewhat distinct problems. One is the paving of the streets of our larger cities, and the other is the construction of country, town, and village roads. In the larger cities, where wealth is centered, more costly pavement can and should be used, than in the country and smaller towns. In the rural districts less expensive road materials may be used, which will prove scarcely less satisfactory than the more costly pavements of the city.

Stone furnishes the very best foundation for highways, whether they are constructed of macadam, granite blocks, brick, or asphalt. In the cities the materials used for road construction above the foundation are macadam, asphalt, granite blocks, and paving brick. Cheapness enters, as a controlling factor in the use of materials, here as it does elsewhere. The ordinary alderman or legislator, if he knows anything about road construction, frequently forgets it in his ambition to perpetuate himself in office, with the result that cheap and not durable materials are used for this important work. In the larger cities macadam is little used, where the road is subject to heavy traffic. Cedar blocks have likewise been discarded as being too temporary and unsanitary. Until the last few years granite, limestone, and quartzite blocks were very largely used on streets subject to heavy teaming, but the large army of wheelmen, in the cities, are strenuously opposing the further use of these blocks for street paving. The power which they wield has be-

come such a potent factor in local elections, that the alderman, who is ambitious for future office, cannot ignore it. Through this influence, and a general dislike among pedestrians for stone pavements, the market for granite, quartzite, and limestone blocks has gradually diminished, until it has sunk to almost insignificant proportions.

Asphalt, which is taking the place of block pavement, needs either concrete or rough stone for foundation. Very little labor is required in shaping stone used for this purpose, and therefore the lessened demand for granite blocks is far from compensated for. Macadam is being used in thousands of the smaller cities and towns for road construction, but owing to the lack of a proper understanding of how to construct roads out of crushed rock, it has often proved unsatisfactory. The macadam on a road should be sufficiently thick to sustain, without injury, ordinary heavy traffic and should be so built that it will shed the water which falls upon it. It should also be constructed out of material which is durable and will withstand to a high degree the abrasion of heavy teaming. All stone is not suited to this purpose. Rock which is soft will powder under the horses' hoofs, forming a fine dust, which will rise in stifling clouds during the dry months of summer, and form inches of mud during the wet months of spring and fall. The stone should not only be sufficiently hard to withstand abrasion, but it should also have a composition which furnishes the proper constituents for cementing together the fragments of which the macadam is composed.

The same error is made in this state, as elsewhere, in using stone which is most easily accessible, whether suitable or unsuitable. In certain cities of the state the council expends enough in the repair of a macadamized street, during the first ten years of its use, to entirely rebuild it. This may be attributed in many instances to the use of unsuitable materials. Local politics often control and the people are helpless to prevent.

CURBING.

There has been a large demand in the cities during the past few years for curbing. Some of the quarries within the state

are now being worked almost exclusively to supply this demand. Concrete is being substituted in some places for stone, but it has not been in use long enough to warrant making comparisons.

LAKE SHORE CONSTRUCTION.

The government piers, breakwaters, and cribs along the shores of Lakes Superior and Michigan furnish a large demand for rough stone. Certain quarries in Door county and elsewhere are now being worked almost exclusively for these purposes. A stone used for these purposes should have the capacity to withstand the attrition of the waves and should be relatively insoluble.

BRIDGE AND CULVERT CONSTRUCTION.

There is a constant demand for stone in the construction of bridges and culverts. The railroads furnish a large demand, and for the most part they own and operate the quarries from which this demand is supplied. But there still remain thousands of bridges and culverts along the public highways, the stone for which must be furnished mainly by private quarries. Each year many bridges and culverts are replaced and new ones are built. There is an urgent need in this direction for the use of better stone and more careful masonry.

MISCELLANEOUS USES.

Among the miscellaneous uses the largest demand is, probably, for flagging for sidewalks. In the larger cities the sidewalks are built mainly out of large limestone or sandstone flags. Concrete has supplanted the use of stone in many places, but, as in the case of curbing, it has not been in use sufficiently long or fully enough investigated to warrant making comparisons. In the production of concrete in this state, the finer product of the crushed quartzite is largely used. In this way the stone from the quarries is to some extent utilized in the manufacture of artificial products. Retaining walls, mounting blocks, fences, hitching posts, steps, and many lesser uses are sources of a constantly increasing demand for stone.

CHAPTER II.

NECESSARY CONSIDERATIONS IN THE SELECTION OF STONE.

There are three important considerations, aside from cost, necessary in the selection of stone: (1) Color; (2) The atmospheric and other conditions to which the stone will be subject; and (3) The inherent qualities of the stone, which make it best suited to withstand these conditions. In the first part of this chapter we will consider the color of the stone.

I. COLOR.

Rocks from the same quarry often differ very widely in color. One of the difficulties in constructing a large building is to obtain stone which is perfectly uniform in color. The predominant colors are white, gray, brown, red, yellow, buff, black, and green, but a formation is seldom found in which one color is persistent over any considerable area. Even the Oolitic limestone from the Indiana quarries is colored a number of shades of blue and buff.

The color of a rock is mainly a composite color formed by a blending of the different colors of the constituent minerals. Occasionally a rock is very unevenly colored, each mineral particle being sufficiently large to retain its distinctive color, as in the case of certain of the coarse-grained granites. But in the igneous rocks, as a whole, the color approaches nearer to what has been called a composite color than it does in any of the other rocks. The gray color of granite is not a uniform gray,

but is rather the resultant color of an intimate admixture of black and white mineral particles. The color of granite is discussed in a following chapter. (See Appendix, Chapter I.)

The color of the sedimentary rocks is due mainly to included iron and carbonaceous matter, which imparts to the rock various shades of blue, brown, buff, red, gray, and black. The iron usually serves as a cement, binding the original particles together, although it may also be an original constituent in the shape of finely disseminated particles. Frequently the color varies widely, not only in the same quarry, but even in the same bed. The coloring matter occasionally distributes itself very curiously through the different beds forming what is known as variegated stone. At times the color is distributed through the beds in regular bands, while it not infrequently forms very irregular, fantastic figures. Occasionally a white sandstone occurs in which large and small brown spots may be observed, and again a brown sandstone may be found having similar white spots. Certain beds in a quarry may have a delightfully cheerful, uniform color, while others above and below may be dull and somber.

The color of a rock when freshly quarried may be almost perfectly white, but after a few months of exposure in the wall the color may change to a buff or the stone may be streaked with irregular patches of brown. Such discoloration depends chiefly upon the presence of impurities within the stone itself. The yellow color of many limestones is often due to the presence of finely disseminated iron sulphide. If stone contains either the sulphide or the carbonate of iron, discoloration is a natural consequence of exposure to the atmosphere, and such stone often weathers buff after a few years' exposure. The oxides of iron are more stable compounds than the sulphide or carbonate and are less liable to alteration.

Discoloration on the face of a wall may be due to impurities in the mortar, cement, or brick used in the construction, which are brought to the surface through capillarity. The committee appointed to investigate the cause of the brown iron oxide stains on the walls of the new State Historical Library building at

Madison, Wisconsin, concluded that the only sufficient source of ferrous iron was the cement used in the construction of the wall. The Bedford limestone was reported to be practically free from ferrous iron, and the cause of the iron staining was attributed to the cement used in the back wall. How much of the staining, in this case, should be attributed to impurities in the stone and how much to the accessory materials, is still a question, yet it is believed that not infrequently the iron rust discoloration on the face of a stone wall, may be due to impurities in the mortar, cement, or brick, rather than to impurities in the stone. A common preventative against the ferrous iron in the brick or mortar of the back wall coming to the surface, is a coat of asphalt between the back wall and the stone facing. A better precaution would be to select lime, cement, and brick in which it is certain that ferrous iron is not present.

The dark colored rocks, brown sandstone for example, after long exposure, occasionally take on a lighter tint, owing to the loss of iron oxide from the exposed surface. This decoloration is not an important consideration. As a rule, the discoloration, occasioned by the decomposition of iron sulphide and carbonate, is deleterious only to the light colored rocks. The dark and the gray limestones are both often discolored by spots or irregular efflorescent patches, usually calcium or magnesian sulphate, which appears as a white precipitate on the surface. As previously explained, this is due to the evaporation of the interstitial water, which comes to the surface through capillarity. The color of a rock, as it comes from a quarry saturated with water, is generally different from that of the seasoned rock. The water generally changes the color of a white or buff stone to a bluish gray.

Very often, through long exposure in the quarry, a rock, such as the blue limestone of the Trenton formation, may be partially weathered along the joints, leaving a blue core surrounded by a buff colored margin. Near the surface, these beds, which were originally blue, are often completely altered to buff, while deeper in the quarry they are but little changed.

The manner in which a stone is dressed sometimes affects the

permanency of its color. A rough dressed stone furnishes a million places for dust and dirt to lodge, while a smooth dressed stone is free from such lodgment places. Thus there is less danger of the original color being obscured in a rock with a smooth dressed face, than in one with a rough face. On the other hand, any irregularity in color, that may be inherent in the stone, is emphasized on the smooth more than on the rough dressed face. These imperfections may be more unsightly than the discoloration occasioned by the lodgment of smut and dust, and in such a case, it would be preferable to rough dress the stone.

There are many other variations in color among the sedimentary rocks, but the above mentioned are the principal ones with which we may come in contact in our study of Wisconsin building stone.

The market value of a stone is often influenced by its color, without regard to its strength and durability. The market value of stone, as well as other products, is controlled by the law of supply and demand. The supply of a certain kind of stone may remain constant, but the demand for that stone may fluctuate on account of fashion. In stone, color, as a rule, is the only element which is subject to the influences of fashion. Until a few years ago brown stone was all the rage, both for business blocks and residences, but the eye became weary of gazing at long rows of somber colored buildings, and the fashion changed to light colored stone, where it now rests, awaiting the next reversal. Immense quantities of light colored stone are now being used, but its prestige is only temporary. The tide will swing back again in a few years, and it is to be hoped that the halt will be made at a place where the use of neither dark nor light colored stone will be supreme. A judicious use of both will serve to relieve the monotony occasioned by long rows of somber brownstone buildings or the dazzling glare of white limestone and marble.

In our large cities, other things being equal, the permanence of color, considering both external and internal causes, ought to be a factor worthy of consideration in the erection of flats and residences, but it scarcely warrants serious attention in the con-

struction of business blocks. A white limestone or marble structure, erected in the midst of the business portion of a large city, soon loses its original color, becoming gray and dingy from the smoke and dirt that fills the air. If the limestone is bituminous and contains a small amount of oil, it will be certain to collect all the dust and smoke which chances to fall upon it. In the suburban and residence parts of a city and in the rural districts, where both smoke and dust have little effect, the original color will not suffer so much from external causes alone. In the business section of our large cities, the walls of all the buildings become so begrimed with smoke and dust that it is barely possible to tell which were originally constructed out of light and which out of dark colored stone. One has to familiarize himself with the different shades of brown and gray, characteristic of different colored stones, after they have been steeped for years in a smoke and dust laden atmosphere, in order to be able to determine their original color. On the whole, the darker colored stone shows much less than does the light colored, the effects of the smoke and dust. It is true that long rows of brownstone buildings are not very enlivening, but since all buildings generally approach this color after a few years, without respect to their original color, this has little weight as an argument against the use of brownstone. The only consideration in the selection of stone to be used in the business portions of a large city, ought to be one of strength and durability. In the residence portions of a city, where beauty is one of the chief ends of architecture, a judicious scattering of buildings constructed out of light and dark colored stone, adds very materially, not only to the appearance of the street as a whole, but also to the beauty of the dwellings individually.

Thus far the discussion of color has pertained solely to stone used in outside constructional work. When used for inside ornamental purposes, a stone does not suffer materially from atmospheric agencies, and the color will ordinarily remain permanent. The selection of stone, then, becomes merely a question of taste. A color which harmonizes with the surroundings, or matches the other work, is generally considered most appropri-

ate. In the flooring or steps, the color should not be the controlling factor, but rather the capacity which the stone has to withstand abrasion, and the tendency which it has to become slippery.

For monumental purposes the taste of the purchaser is again the main, controlling factor, although durability should be first. The stones used for monuments are mainly igneous and metamorphic (granite and marble), and should not contain elements which will result in discoloration. If a stone contains such elements it is a serious defect. The fact that most of the water which falls on a granite monument is shed by its polished surfaces, prevents decomposition, thereby lessening the danger of discoloration.

In the more common uses to which stone is put, such as road making, sidewalks, retaining walls, cribs, break-water, bridge abutments, etc., the element of color scarcely enters. In the case of retaining walls and sidewalks, which are partially ornamental in nature, color sometimes enters as a lesser consideration.

II. EXTERNAL CAUSES OF DECAY.

In the selection of a stone for any purpose a consideration of the climatic conditions under which it is to be placed, is of very great importance. A uniform climate in which the temperature is always above the freezing point is most favorable to long life. A dry climate is conducive to stability, while a moist or humid atmosphere promotes decay. A stone which will withstand the vicissitudes of a moist, temperate climate, where there are long seasons of alternate freezing and thawing, short hot summers and cold winters, must be of the most enduring kind. The well preserved condition of the monuments of Rome and other cities of the Mediterranean basin, after centuries of exposure, is not due so much to the inherent qualities of the stone as to the warm, dry atmosphere. The obelisk of Luxor, which stood for centuries in Egypt without being perceptibly affected by the climate, is now filled with small cracks, and

blanched, after but forty years' exposure in Paris.[1] The same is true of the obelisk in Central Park, New York, from which many pounds of small fragments have fallen.[2] So rapid was the work of disintegration that it became necessary, in order to secure any degree of preservation, to coat the obelisk with a preparation of paraffin containing creosote dissolved in turpentine.

The external forces of destruction may be conveniently considered in two classes, those that produce changes through chemical action and those that produce changes through mechanical disintegration. In the case of disintegration the adhesion between the particles, or the cohesion of the particles themselves, is overcome, and the rock crumbles into sand or powder. In the case of chemical changes, the identity of the mineral particles themselves is destroyed by the minerals being broken up into other compounds. The following is a general classification of the agents of disintegration and decomposition:

I. AGENTS OF MECHANICAL DISINTEGRATION.

A. TEMPERATURE CHANGES.

(1) Unequal expansion and contraction of the rock or its mineral constituents.

(2) Expansion and contraction of the included water, occasioned by freezing and thawing.

B. MECHANICAL ABRASION.

(1) Water.
(2) Wind.
(3) Feet.

C. GROWING ORGANISMS.

D. MAN'S IGNORANCE AND INCAUTIOUS METHODS OF WORKING AND HANDLING STONE.

[1] A. A. Julien, 10th Census, Vol. V., p. 370.
[2] Bulletin N. Y. Museum, Vol. II., No. 10, p. 385, J. C. Smock.

II. AGENTS OF CHEMICAL DECOMPOSITION.

A. WATER—SOLVENT ACTION.

B. CARBON DIOXIDE.

C. SULPHUROUS ACIDS.

D. ORGANIC ACIDS.

TEMPERATURE CHANGES.

Injury to a stone through changes in temparture are occasioned in two ways: (1) By the unequal expansion and contraction of the rock itself; (2) and through the expansion and contraction due to the alternate freezing and thawing of the included water.

Unequal expansion and contraction of the rock.

It is well known that, as a rule, heat expands and cold contracts. The heat conductivity of stone is very low. A stone a few inches in thickness may be heated on one side to a temperature sufficiently high that it will not bear handling, while on the other side the stone may be comparatively cold. The actual expansion of different kinds of stone has been experimentally determined by W. H. Bartlett,[1] in which he obtained the following results:

Granite .000004825 in. per foot for each degree F.

Marble .000005668 in. per foot for each degree F.

Sandstone .000009532 in. per foot for each degree F.

The diurnal changes in temperature in this latitude are often as much as 50° F., while the annual variation in temperature exceeds 150° F. A difference of 150° F. would make a difference of one inch in a sheet of granite 100 feet in diameter.

Each mineral of which a stone is composed has a different rate of expansion. The igneous rocks, it will be remembered, are composed of several different minerals, while each sedimentary consist mainly of one. The constituents of the former are interlocking, while those of the latter are usually united by a

[1] American Journal of Science, Vol. XXII., 1832, p. 136.

thin coat of cementing material. For these reasons the unmodified sedimentary rocks are usually less injured by the diurnal changes in temperature. Whenever a stone is heated each particle will press unequally against its neighbor with almost irresistible force. When it is cooled stresses are set up, due to contraction, which tend to pull the individuals apart. In this manner forces are constantly at work in the superficial part of the rock, tending to separate the superheated stratum from the cooler portions below. Likewise, due to the inequalities in the rate of expansion in the different mineral particles, stresses are initiated, in rocks having a heterogeneous composition, which tend not only to rupture the individuals but also to separate them from their neighbors. The final result of these alternating temperatures, besides weakening the rock, is to produce small cracks or joints into which water may percolate or roots descend.

The entrance of water and roots materially hastens the work of destruction already begun. But investigation shows, that very great work is accomplished simply through expansion and contraction due to diurnal temperature changes without the aid of water or roots. Merrill, in his "Rock Weathering," cites an instance in Montana where he found "along the slopes and valley bottoms numerous fresh, concave, and convex chips of andesitic rock, which were so abundant and widespread as to be accounted for only by the diurnal temperature variations. During the day the rocks became so highly heated as to become uncomfortable to the touch, while at night the temperature fell nearly to the freezing point."[1] Livingstone reports the temperature of rock surfaces in Africa to rise as high as 137° F. in the day, and cool off so rapidly by night as to split off blocks weighing as much as 200 pounds. The expansive force of heat is well shown in many of the limestone quarries of Wisconsin, where beds from 5 to 6 inches in thickness are for the first time exposed to the heat of a summer's sun. These thin beds become heated throughout their entire thickness and arch up on

[1] Rocks, Rock Weathering and Soils, p. 181, Geo. P. Merrill.

the floor of the quarry, generally breaking and completely destroying the stone.

Many buildings show the effect of weathering on the side exposed to the direct rays of the sun, while the sheltered side remains uninjured. The only rational explanation for this is found in the effects of temperature changes. The movements due to temperature changes are necessarily small, but after centuries of time they must invariably result in the weakening and final disintegration of the stone.

Expansion and contraction of included water through freezing and thawing.

The effects of temperature changes, described above, are little when compared with the action of continued freezing and thawing on a rock saturated with water. The expansive force of freezing water is graphically described by Geikie as being equal to the weight of a column of ice a mile high, or a little less than 150 tons to the square foot. One centimeter of water at 0° C. occupies 1.0908 cm. in the form of ice at 0°C. It is this expansion of about one-tenth that does the damage when confined water solidifies.

Water finds its way into the rocks through openings or hollow spaces which are everywhere present. These spaces, which are all connected in such a manner as to allow the water to flow from one part to another, have been divided, for convenience, into three classes. The first class consists of small interspaces that exist between the grains in the rock, known as pore spaces; the second class consists of those openings in the shape of sheets which form along bedding, jointing, and fissile planes; the third class are those openings, caused by the removal of several or many of the individual grains, commonly known as cavities, caves, or caverns.

We will first consider the relation of the interspaces, known as pores, to the durability of the rock. Ordinarily, the pores are conceived of as being connected so as to form irregular shaped tubes. Naturally they differ very greatly in size, de-

pending upon the fineness of the particles composing the rock and the extent to which the interstices have been filled with secondary mineral matter. In the same rock the pores are never all of the same size, but have simply a general correspondence in size. The pore spaces are classified according to size into capillary and subcapillary.[1] The capillary pores are the larger and the water, which they hold, is known as the water of saturation. Openings included in this class are over .00002 centimeter in diameter.[1] If a rock containing capillary pores is allowed to darin off naturally a portion of the water will escape but another portion will remain which is known as the water of imbibition. The sub-capillary pores are conceived to be of such a size, smaller than .00002 centimeter in diameter, as to contain only the water of imbibition.

All the water contained in the pores of a rock is known by quarrymen as quarry water. The water of saturation is given off with comparative readiness, while the water of imbibition is retained with great tenacity. And the nearer the pores approach those of sub-capillary size, the greater is the tenacity with which the water is retained in the rock. From the above one can readily understand how the particles composing a rock may be so small and closely fitted together, that the pores will be mainly of sub-capillary size. In such a rock the included water will be given off very slowly, and the attendant dangers from freezing will be increasingly great. Further, it may be said that the dangers from freezing will be increasingly great as the pores approach in size those of the sub-capillarv dimensions.

The percentage of pore space will also condition the extent of injury from freezing. It should be kept in mind, in this connection, that a fine and a coarse grained rock, in one of which the interstices are very minute and in the other of which they are much larger, may have the capacity to absorb equal amounts of water. Of two equally saturated rocks, one with 10 per cent.

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[1] Metamorphism of Rocks and Rock Flowage, by C. R. Van Hise, Bulletin of the Geological Society of America, Vol. 9, p. 272.

and the other with 3 per cent. of pore space, in which the pores are of equal size, the former will be in the greater danger of freezing. The percentage of the pore space that is filled with water will also condition the results of freezing. If two-thirds of a rock is saturated more injury will result from its freezing than if only one-third were saturated. If none of the pores are more than 9-10 filled with water, the effect of freezing will be nothing, because the increased bulk will no more than fill the spaces between the grains.

The amount of water contained in the pores at a given time depends, of course, upon the amount of water initially absorbed, the time that has elapsed since absorption, the condition of the atmosphere, and size of the pores. In the walls of a building it is only in exceptional cases that the stone is saturated, but when it is, the water of saturation is, as a rule, quickly removed, except in the lower courses below the water line, provided the pores are of greater than sub-capillary size. It would appear from the above, that the most important factor in estimating the danger from freezing and thawing, is the rapidity with which the rock gives up its included water, which depends, as stated above, mainly upon the size of the pore spaces. The second factor of importance is the amount of water contained in each of the pores at the time of freezing. Third and last in importance is the total amount of pore space. The higher the percentage of pore space, provided the pores are of the same size and the degree of saturation be equal, the greater the danger from freezing.

T. S. Hunt, in "Chemical and Geological Essays," says: "Other things being equal, it may properly be said that the value of a stone for building purposes is inversely as its porosity or absorbing power." This statement has been quoted by various authorities among whom may be mentioned T. C. Hopkins, who says, in his report on the Pennsylvania Brownstones:[1] "Other things being equal, the more porous the stone the greater

[1] Appendix to Ann. Rept. of Penn. State College for 1896, Brownstones, p. 28, T. C. Hopkins.

the danger from frost." Following these and other writers the mistake has often been made of estimating the danger, from freezing, by the capacity which a stone has to absorb water. Likewise the capacities which two stones have to withstand weathering are constantly being compared from the standpoint of their ratios of absorption. Such estimates and comparisons are very misleading, for one should not only know the capacity which a stone has to absorb water, but he should, above all, know the size of the pores. As shown above, the latter factor is of much greater importance than the former.

The injurious effects of the freezing and thawing of the "quarry water" has long been known to contractors, who generally refuse to accept stone, especially sandstone, which has been exposed to the action of freezing before being seasoned. Where it is possible, quarrymen sometimes flood their quarry during the winter months, in order to protect the stone immediately at the surface.

The second class of openings, those formed along bedding, jointing, and fissile planes, permit a freer circulation of water than the pores in the rock. Professor C. R. Van Hise has also classified these openings as capillary and sub-capillary, including in the latter all sheet passages of less than .00001 centimeter in thickness.[2] After an abundant fall of rain, when the snow melts in the spring the cracks and crevices in the rocks cannot carry away the water nearly as rapidly as it collects in depressions at or near the surface, allowing abundant time for the temperature to fall below the freezing point. If the temperature is flunctuating between freezing and thawing, the water will be alternately in a liquid and solid state. In a solid state, the water requires more room than in the liquid, and for this reason the walls of the crack or crevice in which the water has collected, are shoved frather apart by the freezing of the water.

Not only will the cracks and crevices become very much enlarged and expanded through the stresses exerted by the expansion of the water but the stone will also be materially weak-

[2] Metamorphism of Rocks and Rock Flowage, C. R. Van Hise, Bulletin of the Geological Society of America, Vol. 9, p. 272.

ened. The process may begin with an infinitesimally small crack in which the water has found lodgment for the first time. The temperature lowers, the water freezes, and upon the melting of the ice the crack will be found to have widened. Repeat the process and the crack will open still wider. If the process is continued the two walls of the rock will finally be shoved so far apart that the water is no longer retained. The ice acts as a wedge which automatically adjusts itself to the size of the crack, until the opening is sufficiently wide and deep to allow the free passage of the water.

Alternate freezing and thawing of the included water has been one of the most potent causes for the decay of building stone. Especially is this true of that stone which is bedded or otherwise laminated. The most disastrous results from this cause have been observed in stone which has been placed in walls without being properly seasoned, and where stone is laid on edge instead of on the bed. In the first case the stone is materially weakened throughout by freezing, while in the latter, exfoliation or scaling is liable to ensue. The most trying place in a building, in which to place a stone, is at the "water line," where saturation is most common and the greatest alternations of freezing and thawing occur. The conditions are most severe in the case of bridge abutments and retaining walls than elsewhere. In bridge abutments one often finds the course of stone, at the level of the water, badly shelled and broken, while the remaining courses are scarcely injured. It is not uncommon to observe all the courses of a retaining wall in a dilapidated condition after it has been built a comparatively few years. When the snow melts in the spring the water sinks into the ground and issues through every crack and crevice in the wall. As it collects in these places it freezes and wedges apart the laminæ of the rocks.

The danger from parting planes due to the collecting and freezing of water, must not be confused with the danger attendant upon the freezing of water which fills the pores of the rock. The bedding and other parting planes that are ordinarily present in sedimentary rocks, may collect and retain water in a suf-

ficient amount to materially injure the stone, if frozen. Igneous rocks also, occasionally, have fissile or schistose planes, on account of which they are subject to the same danger. The compact thoroughly homogeneous rocks, without bedding or other parting planes, whether sedimentary or igneous, are in less danger from freezing than those in which these structures exist.

Because the sedimentary rocks most frequently have parting planes they are as a class more apt to suffer from the freezing of the water which collects along these planes, than are the igneous rocks. On the other hand they may be as free from these planes as the igneous rocks, and accordingly in as little danger from freezing. Further it has been shown above, that, ordinarily, a rock with relatively large pore spaces, is in less danger from the freezing of the interstitial water than one in which the pores are very small. This leads directly to the conclusion that an ordinarily well cemented sandstone, which is free from parting planes or stratification, and in which the percentage of pore space may be high, but the size of the pores large, is best suited to withstand alternate freezing and thawing, when placed in the wall of a building. It is assumed, of course, that the original strength of the stone is sufficient for the position which it occupies in the wall.

The third class of openings,—caves, caverns, and cavities,—need not occupy our serious attention. Cavities occasionally occur in both the sedimentary and igneous rocks used as building stone, but mainly in the former. They are not known to occasion injury by the freezing of the water that may collect in them, but they slightly weaken the rock and often occasion a roughness of the face, when they occur on the surface. The cavities are also, occasionally, partly filled with impurities, which may injure the rock, through their capacity, either for discoloration or decomposition.

MECHANICAL ABRASION.

One of the most important agents of disintegration in nature is mechanical abrasion. The role which it plays in the destruc-

tion of artificial structures is not nearly as important as that of certain other agents.

Mechanical abrasion is accomplished mainly by wind and running water which work in conjunction with all the other agents of disintegration. The manner in which these agents accomplish their work of wearing away the land, is well known. In like manner the beating of the rain against a stone wall may overcome the adhesion between the rock particles, separate them from one another, and carry them away. These particles may, in turn, as they are carried down the side of the building, wear off other particles with which they come in contact. In the arid regions of the west where sand storms take the place of rain storms, the rocks are carved into the most fantastic shapes by the drifting sand. The action is analogous to that of an endless file, which slowly but surely works its way through huge pedestals of rock. The work accomplished is a maximum near the surface and decreases as one proceeds upward. Houses and other buildings in the temperate climate of Wisconsin are worn but very little by drifting sand. This agent contributes an almost insignificant part to the whole process of disintegration in this state. J. C. Smock,[1] in his report on the building stone of New York, mentions the fact that the ground glass character of many of the window panes in some of the older houses of Nantuckett are due to driven sand. The windward side of many of the monuments in the older eastern cemeteries has lost its polish, while in some cases even the lettering has been destroyed, by this same agent. Where the cemeteries of Wisconsin are situated in sandy regions, the monuments are already beginning to show the effects of wind blown sand. The polish has been dulled and the lettering is becoming indistinct.

Besides being subject to the abrasive action of wind and rain, stone is often used in places where it is abraded by thousands of feet passing over its surface. There is a great difference in the capacity which different stones possess to withstand abrasion. The steps, leading up to the main entrances to the Capitol building at Madison, show very strikingly the effect of foot-

[1]Bull. of the N. Y. Museum, Vol. II., No. 10, p. 386.

abrasion. Sidewalks, pavements, and steps may be seen in every city, which are more or less worn by the constant shuffling of feet over their surfaces.

GROWING ORGANISMS.

It is a very common occurrence to find lichens and algæ covering the surface of the rock in a natural exposure. Trees may also be observed sending their roots deep into the crevices and cracks of the rock, and by their growth and expansion huge blocks are often broken from the parent mass. In some of the softer rocks where apparently no joints exist the writer has observed the finer rootlets ramifying through the body of the rock itself. The fine roots penetrating the rock tend to destroy the adhesion which binds the particles together, and in this manner, after many years, a rock mass may be reduced to fragments. The decaying plants give off organic acids which also aid in the decomposition of the rock.

The surface of a rock is often almost entirely covered with fungi or algæ which are attached almost inseparably to the rock. The most common form of plant growth occurring thus is what is known as the lichen. Lichens have a protective as well as a destructive influence. They often cover the surface of the rock after the manner of a mat, protecting it against the atmospheric agents tending to decompose it. The acids formed by their decay and the mechanical effects of their rootlets penetrating between the grains are a cause of the distintegration of the rock. Algæ also grow on the exposed surface of a rock and often occur on the damp parts of a wall occasioning discoloration, through decay and the lodgment of fine dust particles. Some of the buildings in Wisconsin constructed out of imported, soft red sandstone, are discolored by the growth of an abundance of green algæ, which is a very material objection to the use of such stone.

English ivy, climbing over the ruins of ancient buildings, sends rootlets into every crevice and cranny of the walls and thereby increases the rate of disintegration. The effect of allowing creeping vines such as ivy, to cover the walls of buildings,

may be picturesque, but the practice is certainly injurious to the life of the stone.

MAN'S IGNORANCE AND NEGLIGENCE.

The natural forces of destruction have been very greatly accelerated, either through the ignorance of quarrymen and their total disregard for proper time and methods of quarrying, or through the carelessness of workmen in cutting, carving, and laying the stone used in building construction. There are probably thousands of buildings, constructed out of stone, the lives of which have been shortened at least one-half by improper methods of handling. Many of the once handsome and imposing structures of New York, Boston, and other large cities, after but a century of exposure to the atmosphere, are in a helpless state of decay. This is certainly not due entirely to the handling and setting of the stone, but any inherent weakness in the stone has, nevertheless, been augmented thereby. Certain kinds of building stone unless they have been thoroughly seasoned, are more injured by freezing than others. I have previously mentioned the resistless pressure exerted by water when it passes from the liquid to the solid state. It is sufficient to say that there are many instances where the freezing of a stone, saturated with water, before it has been seasoned, has largely destroyed its usefulness. Where the pressure occasioned by the freezing of the interstatial water is not sufficient to completely shatter the rock, it often loosens the individual grains in such a manner as very materially to lessen its strength. When such blocks are placed in the wall of a building, they become weak spots, where disintegration is most rapid. It is necessary that at least the water of saturation be driven off before the rock is used in the construction of a building. As a rule, quarrymen are acquainted with the effects of frost upon stone which has not been seasoned, and observe the necessary precautions. But there are quarrymen, interested solely in the disposition of their stock, who impose upon the ignorance of the public by selling stone which has not been seasoned, and which is, therefore, unfit for use. Stones should be seasoned not only to escape the danger

of freezing, but on general principles it should always be thoroughly seasoned before being placed in the wall. Men do not build houses out of green lumber, neither should they construct them out of "green" stone.

Improper methods of quarrying also materially shorten the life of stone. In many instances I have found quarrymen moving stone with heavy charges of powder, or even dynamite, expecting to obtain dimension stone for building purposes. The heavy charges of powder not only destroy a large amount of the stone, but they also impair the blocks, which may accidentally remain in sufficiently large dimensions, by shattering the cement and producing incipient joints. The destruction of the cement and the production of incipient joints not only weaken the rock, but also facilitate the entrance of water, with the attendant dangers from freezing, with which we are already familiar. This method of quarrying not only materially lessens the value of the salable stone but hundreds of tons of otherwise marketable stone is absolutely destroyed.

So far as is practicable, when quarrying, advantage should be taken of the natural joints in the rocks. Many of the quarries are traversed by planes of parting, by which the rock is broken into polygonal blocks of such dimensions as to be easily quarried. Whenever blasting becomes necessary, the Knox system of small charges, properly distributed, is by far the preferable method to employ. This method is not free from all the evils of blasting, but is the least injurious of any method yet employed. A still better method of reducing the stone to dimensions that can be easily handled, is by the use of the channeling machine. Especially in working sandstone and soft limestone, this machine can be employed to advantage.

The use of heavy hammers and sledges in splitting the stone, by striking continuously along one line, shortens the life of the stone in the same manner as heavy blasting, by producing incipient joints and loosening the individual grains by cracking the cement. Much care should be exercised in quarrying stone in order to prevent these unnecessary injuries. Nevertheless, considering the carelessness with which stone has been quarried

in the past, it is not so much a wonder that the walls of certain buildings are so soon beginning to crumble as it is that they have not decayed long ago.

The time of cutting and dressing a stone may also influence in a small way its life. It is generally known that, during the process of seasoning, the water, which comes from within the rock and is evaporated at the surface, deposits mineral matter which forms a crust on the surface of the stone. This crust may be formed entirely by the evaporation of the original interstitial water, or it may be added to by water which has soaked into the stone at a later period and been subsequently brought to the surface. That water which has been called the water of imbibition, probably carries a much larger percentage of mineral matter in solution than the water of saturation. The water of imbibition is the last of the quarry water to leave the stone and therefore the crust is not likely to be well formed until the rock has been thoroughly seasoned. If the stone is to be seasoned before being placed in the wall, it is advantageous to have it first cut, dressed, and carved. Not only is it advantageous to observe this rule from the standpoint of future durability, but also from the fact that the stone often works much more readily when first quarried, than it does after it has been seasoned. After a crust has once formed on the stone it should not be broken, because the softer rock underneath, when exposed at the surface, will disintegrate much more rapidly. For these reasons, stone should be worked and finished ready for laying in the wall, before it has become thoroughly seasoned.

The manner of dressing a stone also influences in a small way the length of its life. A stone which has polished surfaces, sheds water much more quickly and is disintegrated much more slowly, than a stone with a rough surface. The stone with a rough surface has many crannies and crevices in which the water collects. Part of the water thus collected is finally absorbed by the rock. It often carries with it carbonic, sulphuric, or other acids which aid in the decomposition of the stone. The addition of water also increases the danger from freezing.

Sandstone that has been hammer dressed, is liable to disintegrate faster than that which has been sawed. This is due to a shattering of the cement, by the impact of the hammer, in those that are hammer dressed. No matter how careful the workman may be, there is a tendency in dressing stone with a hammer to produce incipient cracks which are passageways for the entrance of water from the surface. In general it may be said that polished and sawn surfaces shed water most readily, while the rock faced and hammer dressed stones, on account of their rough exterior, absorb a considerably larger percentage of the water which falls on their surfaces.

The exfoliation of sandstone in the large Eastern cities has been mainly attributed to the fact that much of the stone has been laid on edge instead of on the bed. Laying stone on edge in the wall has been practiced at all times, owing to the greater readiness with which it dresses along the bed than across it. The stratified or schistose rocks as a result of the lamination are often weaker on edge than upon the bed. The lamination increases the facility of dressing the stone along the bed, whereby the cost of working is materially lessened. The greatest tendency to lay stone on edge is encountered in veneer work. It is seldom met with in heavy masonry.

It has been shown that parting planes ordinarily furnish the easiest paths for percolating waters. If these planes are perpendicular to the surface of the earth, they will admit the passage of water much more readily than if they are horizontal. Thus if a block of stone is placed on edge in a wall, there will be greater danger from the freezing of the included water and from the superincumbent pressure, than if it were laid on the bed. In case the stone is laid on edge, the pressure required to split off a lamina will, ordinarily, be much less than if the stone is laid on the bed. In the former case, the force occasioned by the freezing of the water, which collects between the layers, is augmented by the superincumbent pressure of the wall. Where the stone is laid on the bed, the water is less apt to penetrate along the parting planes, and even though it should circulate equally freely in this position, the superincumbent

pressure of the wall would tend to force the expansion in directions parallel to the bedding.

Furthermore, when the stone is laid on edge the differences in texture of the various laminæ are much more strikingly emphasized than where the stone is laid on the bed. This method of laying produces a difference in the rate of weathering of the different blocks as a whole, instead of the minor inequalities of weathering ordinarily shown by the different laminæ, when the block is laid on the bed. In any case, weathering results in intensifying the stratification planes.

One ought to scrupulously avoid laying any stone which shows stratification or schistosity, on edge, in important structures, for the reason, that in this position it is inherently weaker and permits a more ready absorption of water, with the attendant dangers from alternate freezing and thawing. So persistent has been this evil of laying stone on edge, in all parts of the country, that a man who has stone which he desires to place upon the market, but which shows a tendency to scale in old buildings, likes to take refuge in saying, that "that particular stone which shows exfoliation must have been laid on edge." "If it had been properly laid," he says, "the stone would have been in a perfect state of preservation today." Thus it is sometimes a difficult matter for an architect, who has only a knowledge of a stone from the appearance of buildings already constructed, to tell whether scaling has been due to the inherent weakness of the stone, or to improper methods of laying.

AGENTS OF CHEMICAL DECOMPOSITION.

The decomposition of the mineral constituents of a rock proceeds much more slowly, as a rule, than disintegration. The forces which are at work breaking down the chemical compounds have a much greater task to perform than those which have simply to overcome adhesion and cohesion.

WATER.

The active agent, producing chemical changes in the rock, is water. Water is seldom pure, but generally contains, be-

sides mineral salts, one or more acids, either sulphuric, sulphurous, carbonic, or organic, in solution. Thus the water is often a very dilute acid solution. As it percolates through the rocks it dissolves small quantities of mineral matter in one place and deposits it in another where conditions are not favorable for holding it in solution. In this manner immense quantities of mineral matter are transferred from one part of the earth to another. For example, it is largely through this transfer of material by water that sandstone is changed into quartzite. Through these agents the minerals, composing the rocks, of both the igneous and sedimentary series, are decomposed.

In the case of building stone the chemical decomposition of the minerals is so exceedingly slow, that it does not affect the strength or life of the stone, after it is placed in a building.

Only in the case of limestone, dolomite, or marble, or where iron sulphide or iron carbonate occur in other rocks, is there any material deterioration.

SULPHUROUS ACIDS.

In the case of the decomposition of iron sulphide, in the presence of moisture, the formation of iron rust is the most conspicuous, although not the only result. The decomposition of the sulphide produces sulphurous and sulphuric acids, which in the case of limestone, act upon the calcium carbonate, producing calcium sulphate, which is often brought to the surface and deposited as an efflorescence or incrustation.

The sulphurous and sulphuric acid gases are mainly present in the atmosphere of large cities where there is a large consumption of bituminous coal. The action of these acids is largely increased if the atmosphere contains a considerable amount of moisture. In London, where fogs predominate and the consumption of soft coal is very large, there seems to be little question, but that the effect of these gases is worthy of careful consideration. But in the United States, with the exception of a few of the larger cities, the influence of these agents is comparatively small, and needs but a passing mention.

CARBON DIOXIDE.

Wherever water heavily charged with carbonic acid gas is passed through calciferous rocks, more or less of the calcium carbonate is dissolved, lessening the adhesion between the different particles and weakening the rock. In nature the results of this process are very great but the carbon dioxide has scarcely any appreciable affect on the durability of stone used in the walls of a building.

ORGANIC ACIDS.

The influence of organic acids, resulting from decaying organisms, on the life and strength of a rock, especially in the walls of buildings, is so slight as to be scarcely appreciable.

III. INHERENT QUALITIES OF STONE.

Just as there are very many forces constantly operating to destroy a rock, likewise there are very many characteristics or qualities of a rock which give it the capacity to withstand, for a longer or shorter period, these forces. This capacity which a stone possesses to withstand the forces tending to destroy it, is known as *durability*.

A stone having qualities which especially fits it for certain uses may be wholly unfit for others. To be best fitted for use in a country where extreme climatic changes are the rule, a stone must possess certain inherent qualities not required of a stone used in a country where the climate is uniform. A stone which is so placed that it is subject to abrasive action must possess qualities which are unnecessary in stone never subjected to mechanical wear. A stone which is to be encircled with sulphurous or other gaseous fumes should possess qualities not necessary in stone used where these gases are absent. A stone that is to be subjected to intense heat must possess characteristics not necessary in a stone which only experiences ordinary temperatures.

The durability of a rock, under definite climatic conditions, depends mainly upon its (1) Mineralogical composition, (2) Texture, (3) Hardness, (4) Strength, and (5) Structure.

MINERALOGICAL COMPOSITION.

In discussing the mineralogical composition the two main classes of rocks, igneous and sedimentary, will be treated separately.

IGNEOUS ROCKS.

Other things being equal, those igneous rocks, such as granite and rhyolite, that are composed of the most stable minerals, may be considered the most durable. The apparent greater durablity of rhyolte over granite may be attributed to the finer grain and closer texture of the rock, rather than to its mineralogical composition.

Granite and rhyolite are composed mainly of quartz and feldspar, which under ordinary atmospheric conditions are two of the most durable rock forming minerals. Quartz is the more stable of the two and is never decomposed, except as it is taken into solution by percolating waters. Feldspar decomposes very slowly, but owing to the great age of the granite or other rock in which it occurs, it is often in an advanced stage of alteration. The alteration products of feldspar are, as a rule, objectionable, only in so far as they yield more readily to disintegration. The size of the feldspar individuals is a considerable factor in their rate of decomposition. The larger the individuals, the more abundant and open will be the cleavage planes; and since decomposition generally originates along cleavage cracks alteration will be correspondingly more general. But after all, under ordinary conditions, it requires centuries of time for the alteration of the feldspars to be appreciable.

Mica, pyroxene, and amphibole are the next important constituents to quartz and feldspar. Of these, mica is perhaps the least desirable constituent of building stone. The ready cleavage provides an easy entrance for water by means of which disintegration proceeds more rapidly than in the other minerals.

Mica is undesirable in proportion to the size and abundance of the individuals. If present in small individuals, as a subordinate constituent, it is scarcely less durable than quartz and feldspar, but if it is relatively abundant, and in large individuals, it will disintegrate much more rapidly. It should be noticed that the mica above referred to, is not that which occurs in flakes but rather that which is found in crystals. The crystals disintegrate much more readily than the thin flakes or laminæ. Mica does not decompose readily, but the fine cleavage, which the crystals possess, facilitates disintegration.

Pyroxene and amphibole are more durable constituents than biotite, although when long exposed they decompose and disintegrate very slowly. Those varieties rich in iron alter most readily, and on account of the larger percentage of iron oxide resulting from the decomposition, they are classed as undesirable. The fact that greenstone contains, as a rule, a larger percentage of the less durable minerals, pyroxene and amphibole, than granite, accounts in part for its disfavor.

Among the more objectionable accessory constituents of the igneous rocks may be mentioned iron sulphide or pyrite. As previously stated, the variety known as marcasite is liable to the more rapid decomposition, because the iron occurs more largely in the ferrous, than in the ferric state. The ferrous compound is less stable, and readily forms, in the presence of moisture, soluble iron sulphate, which, through capillarity, is brought to the surface and deposited as iron oxide. This is one source of rock discoloration. The amount of actual injury occasioned by the chemical reactions involved in the decomposition of pyrite, is purely a matter of conjecture. Yet it may be safely said that a gradual destruction of the stone results from such decomposition.

THE SEDIMENTARY ROCKS.

The extent to which the durability of the sedimentary rocks is conditioned by the mineralogical composition, depends upon the original mineral constituents and the cementing material by which the particles have been subsequently bound together.

The sedimentary rocks of Wisconsin consist mainly of sandstone, limestone, and dolomite. It is stated in a succeeding chapter (See Appendix, Chapter I.), that the preponderant constituent of sandstone is quartz, and that limestone is essentially calcium carbonate or calcium magnesium carbonate. The relative durability of quartz and calcite under ordinary atmospheric conditions is shown by a comparison of the physical and chemical properties of the two minerals. Such comparisons show that quartz, in itself, is less readily decomposed or disintegrated than calcite.

When aggregated in the form of a rock, the conditions are so changed, that one cannot compare the durability of sandstone and limestone or any other two rocks by a comparison of their chief constituents. In sedimentary rocks the kind and amount of cement enter as important factors. If the cement which binds the grains of a sandstone together, is weak, the rock will disintegrate rapidly under the influence of the atmosphere. Likewise, unless the individuals composing a limestone or dolomite are well cemented, the destruction of the stone by disintegration will be a question of but a short time. It is therefore evident, that a careful consideration of the amount and character of the cement, binding the particles of a rock together, is an important part of the mineralogical examination.

The important cementing materials, in the order of their importance are silica, calcium carbonate, and iron oxide. A number of authors in text books and reports on building stone have treated iron oxide as next in importance to silica as a cementing material. As will be shown this is not true. Silica is the most important of the three cements. Calcium carbonate, although probably in itself less durable than iron oxide, is next in importance to silicia as a cement. Iron oxide, in itself, is more durable than calcium carbonate, but owing to the absence of other necessary qualities, it contributes least to the durability of a rock, and is therefore of least importance as a cement.

The relative value of a cement depends primarily upon its adhesive and cohesive powers. It may be observed that, among the sedimentary rocks, in which the cements are equally abundant,

sandstone, in which the cement is silica, and limestone or dolomite free from any considerable admixture of quartz, are the strongest rocks. The sicileous limestones or calcareous sandstones are of intermediate strength. The weakest are those in which the cement is simply iron oxide. The point which it is intended to emphasize in this connection, is, that a limestone, dolomite, or sandstone, is strongest, when the cement is of the same kind as the original constituents. The reason for this is apparently in the fact that the force that binds like substances is stronger than that which unites unlike substances. Whether weathering proceeds more rapidly through mechanical disintegration or through solution depends more or less upon the kind of cement. For example, a siliceous limestone disintegrates more readily than a pure limestone, while solution may be more rapid in the case of the pure limestone. The walls of buildings contain comparatively little water, and the capacity to withstand mechanical disintegration is the more important quality. The essential thing is to have the particles composing a rock firmly bound together. The affinity between quartz and siliceous cement or between calcium carbonate and calcareous cement is stronger than that which exists between quartz and calcium carbonate. Further it is apparent that the adhesion between iron oxide and quartz or calcium carbonate is less than that between calcium carbonate and quartz. If the particles to be bound together were hematite instead of quartz or calcite, then, under the principle that cohesion is stronger than adhesion, iron oxide would serve the purpose of a cement better than either silica or calcium carbonate.

Calcium carbonate, as a cement or otherwise, is quite readily taken into solution by carbonated waters. The cleavage facilitates disintegration and the inherent softness of the mineral admits of easy abrasion. Silica, on the other hand, is very refractory, is dissolved only with great difficulty under ordinary conditions, and being one of the hardest of minerals, does not respond very readily to abrasion. Iron oxide is one of the harder minerals, is not readily acted upon by water, and has a medium capacity to withstand abrasion.

When silica is the cement of a sandstone or calcium carbonate the cement of a limestone, each grain may be added to until together they form an interlocking mass, resembling the characteristic texture of the igneous rocks.

Originally pure sandstone is thought to be seldom cemented with calcium carbonate. Neither does one find originally pure limestone in which the interstitial material is silica. It may be said that in the intermediate sedimentary rocks, such as calcareous sandstone, the deposition of secondary calcium carbonate has been largely controlled by the molecular force of the original calcite nuclei. It is very probable that the hundreds of feet of almost pure uncemented sandstone of the St. Peter's and Potsdam formations owe their friable character, not so much to the absence of water impregnated with calcium carbonate, as to the absence of calcite nuclei.

Both sandstone and limestone are crystalline in the sense that they are composed of crystalline grains. The current conception that limestone is crystalline, while sandstone is not, is in the above sense erroneous. The shape of the individuals or the method of formation of a rock ought not to govern the use of the term crystalline.

Argillaceous material may constitute a not inconsiderable part of the sedimentary rocks. Omitting reference to those rocks that are purely or almost entirely composed of clay, sandstone and limestone are found, which have their interstices more or less filled with argillaceous matter. Clay also often occurs in thin beds or laminæ, between the rock layers, or as pockets within the stone itself. Clay may occur associated with limestone either finely disseminated through the body of the rock or in thin discontinuous laminæ or leaves between the beds. In either case, on account of the rapidity with which it disintegrates, it is a most undesirable constituent. In addition to the manner of occurrence in the limestone, it is often found in sandstone, in the shape of small lenticular bodies, called pockets.

Argillaceous material is probably most harmful when disseminated through the rock, as an interstitial or essential constit-

uent, and least harmful when it occurs in the shape of pockets. In the former case the rock is not only inherently weaker but disintegrates more readily when exposed to the atmosphere. The injury, in the case of clay pockets, is mainly the unsightly, pitted appearance which is occasioned by the weathering out of the clay. The thin, discontinuous laminæ of clay, often observed in the limestone of the Trenton and other formations, in this and adjacent states, easily disintegrate, leaving the rock in thin beds which in time are often completely destroyed by the alternate freezing and thawing of water, which collects between the layers. The sedimentary rocks contain very few minerals that are especially objectionable. Pyrite is undesirable for the same reasons that were given in the discussion of the igneous rocks. (See p. 36.) The effect of the decomposition of pyrite is greater in limestone than in sandstone, owing to the formation of sulphurous and sulphuric acids, which act upon the calcium and magnesium carbonate, taking them into solution and redepositing them at the surface, as calcium sulphate. This not only discolors the stone, by producing an efflorescence on the surface, but also weakens it.

Bituminous matter in the shape of petroleum occasionally occurs in limestone, and in this form is objectionable mainly because it acts as a dust collector, and causes discoloration.

TEXTURE.

The texture of a rock is an important factor in its durability. Uniformity in size, closeness, and manner of contact of the constituent grains are factors that should be carefully considered. The adhesion in the softer sandstones is largely between the original grains themselves, but in those that are better consolidated the grains are bound together by a cement. The amount of material required to completely cement a rock depends upon the pore space. Theoretically a rock in which the particles are uniform in size and spherical in shape will have the greatest pore space. But this condition is never attained in nature and it may be said that in rocks which approach nearest these conditions the pore space will be greatest. Very few rocks retain the pore space which they originally have, owing

to the fact that the pores are more or less filled by cementing material. The cement decreases the pore space and changes somewhat the texture of the rock. If the cement has the same composition as the preponderant original constituent and is present in sufficient quantity to largely fill all interspaces, the grains will apparently interlock, after the manner of an igneous rock.

The assertion made by different writers, that an increase in the size of the grain is accompanied by a corresponding increase in the size of the pores, is not literally true, because the interstices between the grains of a majority of the rocks are more or less filled with secondary material. Further, experiments upon coarse and fine grained rocks indicate that one cannot tell the porosity of a rock by the size of the grains. A fine grained rock may be as porous as one which is coarse grained. The pores will not be as large in the fine grained rock, but will be more numerous.

The pores in a rock may vary in size, from those that are too small to be detected by the microscope to those which are of sufficient size to be called caves or caverns. Ordinary hackley limestone has derived its name from the small, irregular cavities which are found throughout the rock. Aside from the harmful effects of a high ratio of absorption, rocks which contain any considerable number of cavities are weaker than those which do not contain cavities. It is a very common occurrence to find cavities, in limestone, filled or partially filled with calcite or sometimes quartz. Pyrite, marcasite, sphalerite, and other less common minerals are often associated with calcite in such cavities. Wherever such openings occur in any considerable number they are injurious to the stone. The interlocking character of the mineral particles ordinarily gives greater strength and less porosity to the igneous rocks. Limestone is frequently as closely compacted as granite and the individuals interlock after the manner of the igneous rocks. For this reason they have a very low percentage of pore space and a high crushing strength.

The size and uniformity of the particles influence the man-

ner in which the rock weathers, as is often observed in porphyritic granite. The large crystals of feldspar decompose or disintegrate more quickly than the smaller ones, pitting the surface of the rock. This differential weathering is especially noticeable in a coarse grained rock, composed of several minerals, of different degrees of hardness. The softer constituents will decompose first, leaving very noticeable depressions in the surface of the rock. If the rock is fine grained the depressions are proportionate to the size and hardness of the mineral constituents, and are often so small as to be scarcely noticeable.

Among the sedimentary rocks, differences in the size and compactness of the grains, as well as in mineralogical composition, may ordinarily be observed in each individual bed or lamina. In the matrix of sandstone there are frequently imbedded pebbles of different sizes and degrees of hardness as well as pockets or seams of clay. The pebbles are, as a rule, more durable than the matrix, and therefore resist to a greater degree the destructive forces. As the matrix is worn away, the pebbles remain as protuberances on the stone, until, finally, the cement which holds them in place is so weakened, that they in turn are carried away, leaving small cup-shaped depressions to mark the place where they were originally imbedded. In like manner the soft and more easily disintegrated portions of a rock are indicated by depressions, while the harder parts stand out as small prominences.

Not only do limestone and sandstone from different quarries or from different beds of the same formation vary in durability, but portions of the same layer often weather unevenly. Limestone is frequently interbedded or interlaminated with shale, which disintegrates much more rapidly than the limestone, as was noticed cn a previous page. No better illustration of the weathering of an uneven textured rock can be given than that of a limestone which contains chert nodules and fossils. These impurities cause the stone to weather unevenly, producing an unsightly appearance. As a rule, nodules and fossils cause a more rapid disintegration of the rock, on account of the natural want of coherence between them and the matrix.

HARDNESS.

In the preceding discussion of texture we have been treating largely of the causes for the difference in the strength and durability of stone but have not considered the conditions upon which hardness depends. The hardness of a rock is determined by the hardness of the component minerals, their size and relative abundance, and the state of aggregation. A rock may consists wholly of quartz grains, the hardest of the common minerals, and yet be so soft as to crumble between the fingers. Another rock having the same general composition, but in which the grains are well cemented with silica, may be one of the hardest of rocks. Thus it is plain that the state of aggregation is the main controlling factor in rock hardness. Nevertheless it can be said, that of two rocks in which the grains are of equal size and the state of aggregation similar, the hardness will depend upon the hardness of the constituent minerals. In general the hardness of granite can be compared with that of other granites by a knowledge of their mineralogical compositions. Yet this will only be roughly approximate, because the relative abundance of the different minerals influences decidedly the hardness of a rock. In making such an estimate one should know the percentage of the rock that is composed of each of the constituents.

In the case of the sedimentary rocks, the shape of the grains, their size, and the kind of cementing material are all factors of considerable importance, influencing the hardness of the rock. The cementing material has a hardness of its own, which will either raise or lower the average hardness of the original mineral constituents. The cement further influences the hardness of the rock through the adhesion or cohesion which exists between it and the original particles. The shape of the grains, round or irregular and interlocking, influences very considerably the hardness of the rock. In some rocks the original, rounded grains have been enlarged and interlock to such an extent that the texture approaches that of granite, and the rock is consequently much harder than one in which the grains are simply cemented.

All of the above conditions go to make up the state of aggregation which is the controlling factor in determining the hardness of a rock. The hardness of a rock is controlled by the hardness of the minerals, their relative abundance, and the state of aggregation.

STRENGTH.

The strength of a stone is the capacity which it possesses to withstand stresses applied at its surface. The strength of a rock depends upon a multitude of conditions, many of which have been given in the preceding pages. As in the case of hardness, the strength may be said to be dependent mainly upon the mineralogical composition, size of the grains, and the state of aggregation. The strength is influenced by the presence of cleavage and fissile planes, resulting either from sedimentation or mechanical deformation. As a rule, sedimentary rocks are stronger when pressure is applied normal to the bed than when the pressure is applied in other directions. The igneous rocks have an average strength considerably above that of the sedimentary rocks. The greater strength of the igneous rocks is due mainly to the interlocking character of the mineral particles. If for any cause a rock has been shattered, and the particles thereby loosened from one another, the strength will be greatly impaired. A rock which has suffered in any way from careless handling will not stand the stresses which it would if properly handled. Further, a rock which is completely saturated with water is weaker than one which is dry. The reason for this is not known.

STRUCTURE.

A rock which is free from all joints, sedimentary planes, or schistosity, is much better suited to withstand the active agents of weathering than one which is not. Wherever a rock has actually parted, there we have a place for the accumulation of water. As the water collects during the warm days of early spring and freezes at night, the ice wedge begins its destructive work. Every parting plane in a rock is a place of

weakness, and every crack and crevice is a place where dust and dirt may accumulate, and into which growing organisms may send their roots. A crack once begun opens wider and wider, until finally the rock falls apart.

On account of their laminated character, great care should be exercised in building a wall out of sedimentary rocks. As has been previously stated, none but the strongest stones should be laid on edge in the walls of large buildings. After years of exposure the effect of laying stone on edge is almost certain to show. Parting planes and stratification may scarcely be noticeable in the rock when first quarried, but, nevertheless, these planes are always present in some parts of the stone, and after years have passed may manifest themselves by exfoliation.

CHAPTER III.

MEANS OF DETERMINING THE VALUE OF A STONE FOR BUILDING OR OTHER ECONOMIC PURPOSES.

There are three important methods of determining the value of a stone for building or other economic purposes: (1) Observation on the stone as found in the quarry and adjacent natural exposures. (2) Examination of the stone used in buildings, bridge abutments, monuments, etc. (3) Laboratory tests. No one of these should be considered sufficient in itself, but each should be used in conjunction with the other two.

If a geologist were obliged to choose between these three methods of determining the value of a stone, he would probably find the first method most satisfactory. But an opinion, based upon quarry observations alone, has value depending largely upon the judgment and experience of the observer. It lacks a definiteness and certainty, which can only be supplied by laboratory tests.

QUARRY OBSERVATIONS.

Many important conclusions may result from quarry observations, which cannot be reached through an examination of selected samples. Samples, which are exhibited by quarry owners, are generally taken from the best stock, and often give little idea of the general run of the stone as it occurs in the quarry. The stone often varies quite largely in different parts of the same quarry. The color may be solid and uniform in one part and variegated in another. Certain beds may be uniformly free from lamination, while those immediately above or

below may be distinctly bedded or laminated. There are zones in certain quarries that are characterized by numerous incipient jointing planes, which are noticeable only on the weathered surface. Buildings of long standing may reveal certain of these defects in the stone, but if care has been exercised in selecting the stone, the walls may show no sign of deterioration. The quarry itself is the only place to observe the uniformity of the stone.

The quarry is not only the best place to ascertain the uniformity in color and texture of the rock, but it is also a favorable place to note the permanence in color and the durability of the stone. In the quarry the stone may be examined in its fresh state and contrasted with that of the natural outcrop, which has been subjected, through many years, to the vicissitudes of a changing climate. From these observations one may make comparative estimates of the rapidity with which the rock weathers. Such estimates will, necessarily, be of the most general nature, because no two rocks are subject to precisely the same climatic conditions.

The depth to which disintegration has gone depends less upon the inherent characteristics of a rock than upon its position, with respect to the general level of the country, the climatic conditions, and the length of time through which it has been subjected to weathering action. Under certain definite conditions the rapidity of rock weathering will depend upon the inherent characteristics of the rock. Under different conditions the result may be wholly different. For example, one rock may be so constituted as to suffer more from the extremes of temperature than another, while percolating water may affect the latter more than the former. The same rock under different climatic conditions may in one case show discoloration and in another retain its original color. Under the same conditions one rock may discolor and another remain unchanged. One rock may be affected by organic or other acids, while another will remain uninjured thereby. Thus, as has been previously explained, the cause of decay may be inherent in the rock itself, or a result of external conditions.

The depth of disintegration of rocks naturally elevated above the surrounding country is generally less than those in the low level portions. This is to be partially attributed to the greater rapidity with which disintegrated material is removed from the hills, than from the valleys. Yet it must be borne in mind that rock weathers less rapidly, when it is protected by a mantle of alluvium, as is usually the case in valley plains. In the lower level areas the product of weathering is cumulative, while that of the sloping and more elevated areas remains almost constant.

Further, we must not lose sight of the fact that the disintegration of a very durable rock, through a long period of years, may be greater than that of an easily decomposed rock which has suffered but a few years of exposure. This difference in amount of disintegration is nicely illustrated in a comparison of the rocks of the southern non-glaciated and the northern glaciated regions. The rocks of the glaciated region are less disintegrated than those of the non-glaciated, mainly because they have been subjected to weathering for a much shorter period of time.

There are two additional reasons for the slow disintegration of the rocks of the glaciated region, which must not be overlooked. (1) In many places the rocks have been smoothed and polished, thereby facilitating the passage of the water off from their surfaces. (2) The glacial deposits in many places cover the rocks with a protecting mantle of boulder clay or till. After taking into consideration these two factors, the comparative durability of the different rocks in the glaciated region can be approximately estimated by the depth of the weathering or distintegration.

In the glaciated region disintegration is generally not far enough advanced to furnish any considerable amount of material for transportation by the rivers. Those rocks of the glaciated region, which have been exposed to weathering processes since the recession of the glaciers, thousands of years ago, show clearly any inequalities of texture in the rock. Under a mantle of debris, these differences of texture would fail to appear, even after a much longer period. Under present conditions

the partially weathered surface brings out with exceptional clearness any inequalities in the hardness or texture of the rock. On the weathered surface, the hard parts of the rock generally stand out in relief, while the softer parts are indicated by depressions. Incipient jointing and sedimentary planes can be most readily detected on the weathered surface of a rock. If such a surface shows these structural planes, it is quite certain that they extend into the quarry for some depth, although often invisible. Stone from a considerable depth below the surface, which shows no special structures, when first quarried, may after exposure to the weather for many years, develop fine jointing or sedimentary planes, similar to those observed in the natural exposure. The fact that prominent joints or fissile planes at the surface become so close that they cannot be detected at a depth of several feet, has led to the current belief, among quarrymen, that joints disappear with depth. Although this is certainly true when applied to considerable depths, the general application of the rule has lead to very erroneous conclusions. As a rule the joints do not disappear at the depth to which quarrying is ordinarily carried.

Soft spots, pebbles, fossils, and similar irregularities in texture are revealed by weathering. By careful quarry observations and conservative judgment one may estimate the possible injury from such sources.

In some cases weathering reveals and in others it conceals the presence of injurious constituents. Pyrite or marcasite may be cited as impurities which weathering often conceals. These constituents may often be detected by discolorations on the surface of the stone, but if weathering has proceeded to a considerable depth, direct evidence of their former presence may be completely removed. If quarrying proceeds beyond the zone of weathering the minerals will be found in the rock in their unaltered state. Weathering may cause bleaching, as well as discoloration. Efflorescence and incrustation frequently occur on the weathered surface of limestone. All of these tendencies may be best detected in the natural exposure.

In glaciated areas the hardness may be roughly estimated

by observing the polished or grooved surface of the rock in the quarry. Deep grooves often indicate a comparatively soft stone, while less conspicuous markings, or entire freedom from them, may indicate a hard stone. The clearness and distinctness of the grooves are evidence of durability. In making estimates from such evidence, it is quite necessary, that the character of the stone, its position, and other factors be considered. The presence of lichens growing on the face of an exposed cliff has been thought by some to be indicative of hardness and durability. Unfortunately, this criterion of hardness, when taken alone, has little significance. I have often observed an abundance of lichens growing on the surface of sandstone, which is inherently soft. In such instances the lichens simply indicated that a crust had been formed on the exposed surface of the stone. This crust is frequently very hard, enduring a sufficiently long time for the growth of lichens.

If one is desirous of obtaining a considerable quantity of stone perfectly uniform in color and texture, it is important that he should visit the quarry to assure himself that the amount of the quality desired is obtainable. It is possible for a quarry to be exhausted of its good stone, and for this reason, an inspection is often a valuable precaution.

On the other hand, the stone from a certain quarry, in which a large percentage of the stone is first quality, may have been condemned by the public, because quarryman and contractor have permitted the use of a few inferior blocks, "for the sake of economy." Moreover, in the rush to complete contracts, builders are occasionally obliged to use inferior stone, because of difficulty in securing the proper stone, at the right time. In order to know when one is receiving the best stone that a quarry produces, he should be familiar with the possibilities of the quarry.

OBSERVATIONS ON BUILDINGS, MONUMENTS, ETC.

The value of observations on buildings and monuments constructed out of stone, as a means of estimating their strength and durability, has long been recognized. Nevertheless, on ac-

count of the ease with which they can be made, the value of such observations has probably been overestimated.

OBSERVATIONS ON BUILDINGS.

Contractors and builders are very ready to attribute any noticeable decay of the stone, in the superstructure of a building, to some unknown inherent weakness. As a rule one cannot pass valuable judgment on the durability of a stone merely from an examination of buildings constructed therefrom. It must be remembered that stone which is durable under ordinary circumstances, may be badly injured and its life materially shortened, through rough or careless quarrying, handling, and dressing. The size of a building, its location, and the care which is exercised in laying the stone in the walls, are all factors in the life of the stone. The weight of the superstructure is thought in many instances to hasten the rate of decay of the stone in the lower courses, and it is certain that blasting, the use of heavy hammers, and improper methods of dressing, very materially shorten its life. The stone used in the construction of many buildings is very carefully laid, not a block being placed on edge. Other buildings are constructed with the utmost carelessness, no regard being had for the method of dressing or the manner of laying. Two buildings, constructed with equal care, from the same kind and grade of stone, if subjected to different atmospheric conditions, may show a very great difference in the rate of decay. A building in a large city is subject to different conditions than one in the country. One building may be so situated as to be fully protected from the prevailing storms, while another may be so situated that it suffers from every change of weather.

Further, one seldom knows, from an inspection of a building, whether the stone in its construction, is first, second, or third grade. It is not an uncommon occurrence, for the stone from an entire district to be condemned, because certain structures, built from *third* grade stock, have not proved as satisfactory as other buildings, in which number *one* stone, from another district, has been used. Every quarry has more or less second and

third grade stock, which, although suited to a variety of purposes, can not be used for all purposes. Unfortunately these poorer grades of stone are often used in the fronts of buildings, or even carved for the finer parts of the architectural work. After stone once becomes a part of a building, people do not stop to distinguish different grades, but charge all imperfections against the quarry, as a whole, from which the stone was taken. Sometimes the entire area, including several quarries, has to suffer. If a building, constructed out of third grade stone, becomes shabby in a few years, it is not to be wondered that the quarry is condemned. It is generally understood that two or three different grades of lumber are obtained from a single tree. But because some one finishes his house with the rough, knotty product, people do not condemn the forest, from which the timber was taken. Neither should a quarry or a quarry district be condemned because third grade stone is occasionally used in the construction of a building. If second or third grade stone was purchased as first grade, then the quarryman was probably to blame. If the stone was bought as second or third grade stock, the purchaser and not the seller should be responsible.

The time element, or age of a building, is a very important factor in drawing conclusions as to the durability of the stone used in different buildings. Very few of the important stone buildings in Wisconsin are over fifty years old, and the majority have not been built over twenty-five or thirty years. Many of them do not exhibit the first sign of decay, but others are already beginning to show the effects of exposure to the atmosphere. But, as a rule, the actual disintegration is so small, that we are content to examine the structures, in a search for the beginnings of decay. When a few hundred years have passed and there still remain the walls of our public buildings, it will be easier to tell which, of the many Wisconsin building stones, is best adapted to withstand the changing conditions of the north temperate climate. The great public buildings ought to be constructed out of materials that will not crumble and decay in a few years. They ought to stand for centuries, and the

state that builds for the present, heedless of the future, has not reached the highest development of the present generation.

OBSERVATIONS ON MONUMENTS.

Indications of the durability of different monumental stones, can be found by a careful examination of monuments erected in the cemeteries of this and adjacent states. The oldest of these monuments are built of marble, it being only within a comparatively few years that granite has come into very general use. But so rapid has been its acceptance that at the present time, marble is seldom sold except in rural districts. The comparatively recent date of the erection of the granite monuments leaves us without the necessary time element in comparative estimates of durability.

Nevertheless it is worthy of note, that some of the imported granite monuments, that have been erected for a number of years, are gradually losing their polish, and even now have finely pitted surfaces. Monuments that are so situated, that they have been exposed for years to the winds carrying fine particles of sand, in suspension, frequently have their polished faces dulled, and the lettering obscured. A monument is often more rapidly disintegrated on the side which is exposed to the direct rays of the sun than on the opposite side. This is explained by the diurnal expansion and contraction, due to the heating and cooling of the stone.

The freedom of the stone from incipient joints, segregations, nodules, or other irregularities in texture, can be very readily detected on a polished surface. The degree of polish, which a stone will take, and the contrast in the hammered and polished surfaces, can be best judged from the finished work. It is necessary at all times, in making comparisons, not to let the elaborateness or excellence of the workmanship influence the judgment.

OBSERVATIONS ON MISCELLANEOUS USES.

The suitability of a stone for road construction, either in the shape of blocks for paving or crushed rock for macadam, may

be judged to a large extent by the manner in which the material, in previously constructed roads, has withstood heavy traffic and frost. The manner in which the road has been constructed, and the extent to which it is used, must both be considered. In the early stages of road making, as in all other public undertakings, it must be expected, that all kinds of material will be used. That this has been the case in the construction of many of the macadamized roads of today is evidenced by the fact, that after but a few years of use, many of them are in a very unsatisfactory condition. Much can be learned as to the cause by an investigation of the materials used and the method employed in construction.

An inspection of bridge abutments, curbing, sidewalks, etc., that have been built for a number of years, is often valuable in determining the sutability of the stone for these purposes. If unsuitable stone has been used for curbing purposes, it can generally be detected after a number of years, either by its breaking off at the water line or shaling along the bed. Any tendency to shale or crack is generally brought out when a stone is used in a bridge abutment. If a stone wears smooth and slippery or is easily abraded it can be detected by an examination of steps and sidewalks built out of the stone.

LABORATORY TESTS.

One who is fully acquainted with the physical characteristics of a stone and knows the conditions under which it is to be placed, can predict with a considerable degree of accuracy, without inspecting the quarry or examining buildings of long standing, the results of exposure to the atmosphere. Owners of new quarries ought not to anticipate a very extensive sale for their stone, before it has been thoroughly tested in the laboratory. Before extensively opening a quarry, the characteristics of the stone ought to be carefully determined by a complete series of laboratory tests. Architects and builders should rightly demand that any stone, which they use, be thoroughly tested. No little danger often arises, because the precaution of having stone tested before being used, has been neglected.

Quarrymen as well as architects neglect laboratory tests in the rush to place their stone upon the market. Through the inherent desire in our people to "build a city in a day" they defer the testing, "trust to luck," and "guess it will last as long as I live." Not until the buildings begin to look shabby and show signs of decay, do they stop to consider the value it would have been to have had the stone previously tested. For these reasons the most valuable part of this report, to builders and contractors will be Part II., Chapter VIII., which is a complete discussion of the physical tests performed in the preparation of this report.

The important laboratory tests may be considered under three general heads, viz.: 1. Chemical; 2. Microscopical; 3. Physical.

CHEMICAL.

By means of chemical analysis one may determine the exact composition of a rock in terms of the elements that compose it. The presence and relative amount of any deleterious substance may be ascertained by such an analysis. For example, it is possible, by chemical analysis to determine the presence of ferrous iron in distinction from ferric iron. The percentage of magnesium carbonate in a limestone can be determined only by a chemical analysis. The presence of argillaceous material, and the proportion which it bears to the total mass, can best be determined by this method. In general, the only means at hand to determine accurately the composition of a rock is by chemical analysis. Thus it is plain that the chemical analysis is a valuable and often indispensable auxiliary in the consideration of the qualities of a building stone.

MICROSCOPICAL.

Much may be learned of the structure, mineralogical composition, and general character of most rocks by a careful examination of the hand specimen, especially with the aid of a hand lens. Structures are brought out by such an examination which might otherwise pass unobserved. This method is quite satisfactory for determining the main constituents of the very

coarse grained rocks, but most rocks are, as a rule, so fine grained, that the structures and mineralogical composition can only be accurately determined by the use of a compound microscope. For this purpose thin slices are cut from the rock sample, ground down until almost transparent, and mounted on an object glass, for inspection.[1]

The microscopical examination is of much greater practical importance and less expensive than the chemical analysis. By means of the microscope and thin section, one can determine the two most important factors in the consideration of building stone, the mineralogical composition and the state of aggregation. By this method one can also distinguish very readily the unaltered sedimentary, igneous, and metamorphic rocks. Each mineral has its peculiar optical characteristics by which it may be distinguished from its associates. Exceedingly small mineral particles may be identified by the aid of the microscope. The presence of impurities may be recognized. The closeness with which the grains have been cemented, the kind and amount of cement, the manner in which the grains interlock, and other important characteristics may be determined by a careful microscopical examination of the thin section. The relative abundance of the minerals, and even the chemical composition, can be roughly estimated. The presence of cracks, strains, gas bubbles in quartz, etc., may be detected, and if judicously used, such observations may aid in estimating the durability and strength of a rock. Cracks and strains are thought to be often the result of stresses occasioned by cutting and grinding the thin section. For this reason such observations can be used only with a limited degree of certainty. It is still a question as to how great danger from exterme heat a stone may be in due to the presence of numerous gas bubbles.

The greater significance of the mineralogical composition over the chemical, makes the microscopical examination of relatively greater importance. It is our purpose to give careful

[1] For a description of the method employed in cutting these sections of rock, see "Microscopical Physiography of Rock-Making Minerals," by Rosenbusch-Iddings, pp. 1-3.

attention to the microscopical examination of the different building stones, described in succeeding pages.

PHYSICAL TESTS.

The purpose of the physical tests is to determine by artificial methods the strength of the stone and the capacity which it actually possesses to resist the destructive forces which are encountered in actual use. In a country where buildings are new and the stone has not been in use for any considerable time, it is necessary to resort to artificial means of determining the strength and durability of the stone. On account of the improper methods of quarrying, handling, dressing, and laying which are practiced in many places, one often hesitates to take the signs of decay in buildings, as evidence of inherent weakness in the stone, and he must turn to the physical tests, performed in the laboratory, as a more rational basis for judgment.

It is a simple matter to determine the strength of a stone, but difficulty is experienced in artificially estimating the durability. The difficulty arises from the impossibility of placing the stone under conditions exactly similar to those, which the stone experiences in actual use. The natural conditions change each day, and instead of one, there are generally several of the many forces operating at the same time. Moreover, it is not practicable to attempt the measurement, quantitative or qualitative, of the actual changes produced by normal atmospheric conditions. It is necessary to exaggerate normal conditions, so that there will be accomplished in a brief period of time, what is accomplished during a long period under ordinary conditions.

In order to ascertain the strength and durability of a stone, it should be subjected to the following tests:

A. Strength Tests.

1. Crushing strength.
2. Transverse strength. Modulus of rupture.
3. Modulus or coefficient of elasticity.

B. *Durability Tests.*

1. Specific gravity.
2. Porosity.
3. Weight of the stone per cubic foot.
4. Effect of extreme heat.
5. Effect of alternate freezing and thawing.
6. Action of carbonic acid gas.
7. Action of sulphurous acid fumes.

Strength Tests.

Crushing Strength—The principal test which has been employed up to the present time, for determining the suitability of a stone for any particular use, has been the compressive or crushing strength test. Many quarrymen do not know that it is possible to determine artificially any of the other qualities of a stone. A high crushing strength is often taken as certain evidence of the durability of a stone, and the relative durability of different stones has often been measured by a comparison of their crushing strength. This is a gross mistake, for not infrequently a stone, having a low crushing strength, is more durable than others which are stronger.

In the absence of the other tests the value of the crushing strength test has been greatly overestimated. It has been computed that the stone at the base of the Washington Monument, the highest structure in the world, sustains a maximum pressure of 22.658 tons per square foot, or 314.6 lbs. per square inch. Certain contractors require a stone to withstand twenty times the pressure to which it will be subjected in the wall, while others only require ten times that pressure. Even if requiring a factor of safety of twenty, the strength required for a stone at the base of this monument would be only 6,292 lbs. per square inch. The pressure at the base of our tallest building can scarcely exceed one-half that at the base of the monument, or 157.3 lbs. per square inch. According to the above estimate, stone used in the tallest buildings does not require a compressive strength above 3,146 lbs. per square inch. There is

scarcely a building stone of importance in the country that does not give a higher test than this. Ordinary building stone has from two to ten times the maximum required crushing strength. A stone, having a crushing strength of 5,000 lbs. per square inch, is sufficiently strong for any ordinary building.

It is difficult to say just how the strength of a stone will be effected by long, continued pressure much below its ultimate strength. We know that the cumulative effect of hammer blows in one place on a rock will finally break it, and that a stone which has been placed under heavy stresses and relieved will not stand its average maximum load when placed under the same stresses a second time. The question which naturally arises then, is to what extent will constant pressure lower the crushing strength of a rock? Or will its capacity to withstand pressure remain constant after it becomes adjusted to the new conditions? These are questions to which I am unable to give any satisfactory reply. There appear to have been no experiments performed to ascertain the result of constant and prolonged pressure on building stone, but it is thought that experiments in this direction would prove not only interesting but also profitable.

Further, there are no data by which we can estimate the result of high temperatures on the crushing strength of rocks. Is it not possible that in the large fires of the cities, the pressure of the superincumbent wall may increase the cracking and exfoliation in the lower courses, produced by the intense heat?

The main value of the compressive test is in indicating the purpose to which a particular stone is best suited. In the case of arches, the great pressure combined with an unequal distribution of the load, often causes them to crack. In very large buildings, single columns and blocks are often required to carry huge masses of superstructure. Bridge trusses are often supported on blocks of stone, on which all the pressure of the superstructure is concentrated. In all these cases a stone is required which has a relatively high crushing strength.

The actual strength of a stone can only be determined by

carefully executed laboratory tests. We cannot draw conclusions, regarding the strength of a stone, from the examples of cracking or breaking observed in the walls of buildings. Prof. Hall, writing on this point says: "A little inequality in the bedding may produce such a result (breaking or cracking), when, if evenly bedded, the stone would have borne many times the load it has sustained. In a large and heavy building it is all important that the foundations be firm and unyielding, for on this depends the integrity of the entire structure. Beyond this it is important that the stone be evenly cut so that the bed of each succeeding block should rest evenly on the one below it. From an inequality in dressing two adjacent blocks, . . . I have seen the superincumbent block of granite cracked quite through."[1]

Such cracking is obviously not due to any weakness in the stone, but to the manner of laying, in which the central portion of the block was unsupported and subject to abnormal stresses.

To obtain the crushing strength of a rock it is customary to use cubes that are approximately 2″x2″x2″. Gen. Gilmore performed experiments to show that the crushing strength per unit of area varied with the size of the cube tested, and constructed an empirical formula for the purpose of reducing all tests to crushing strength per square inch on two inch cubes. It has lately been shown that Gen. Gilmore's formula does not hold in practice, but, on the contrary, that the crushing strength per square inch is constant, irrespective of the size of the cube tested.

The care used in the preparation of the cubes influences very materially the results of any series of tests. Cubes that are prepared, either with a hammer or a chisel, are often shattered, through the production of cracks and loosening of the grains. Cubes that are prepared by sawing or rubbing will show a much higher crushing strength than those prepared with the hammer or chisel.

In the preparation of this report approximately two inch

[1] Thirty-ninth Annual Report of the New York Museum of Natural History. Report on Building Stones, by Prof. James Hall, pp. 213-214.

cubes were used for the crushing strength tests. In some instances the cubes were prepared by sawing or rubbing at the mills where the quarries are located; but owing to lack of facilities, it was necessary, in a number of instances, to prepare the cubes in the laboratory of the University of Wisconsin. The details of the method employed in the preparation of the cubes is omitted as being unessential. The cubes were sawed from blocks which were free from any perceptible imperfection, and afterwards the bearing faces were rubbed down until they were smooth and as nearly parallel as the facilities at hand for rubbing would allow.

After the cubes were prepared they were allowed to dry before being placed in the testing machine. In order to distribute the load more evenly thin strips of blotting paper were inserted between the bearing faces and the steel plates. The cubes were crushed at the University of Wisconsin and Purdue University, Lafayette, Indiana, mainly in 100 and 300 thousand pound Riehle testing machines. During the test, the compression due to each increment of 500 or 1,000 pounds was obtained by means of an Olson compressometer. From these readings the modulus of elasticity was computed. The load at which the cubes were first cracked, as well as the ultimate strength, was carefully noted. The manner in which the cubes broke, quietly or explosively, and the perfection of the pyramids, were also recorded. From the ultimate strength of the sample the crushing strength in pounds per square inch was computed. The results of these tests will be found in Part II., Chapter VIII., Table II.

Transverse Strength—The transverse strength of building stone is of far greater importance in masonry construction than would be supposed by the very meager data, which are obtainable from the numerous building stone reports which have already been issued. The broken lintels, caps, and sills which are so conspicuous in many of the larger buildings in this country, indicate the necessity for a more careful use of stone for these and similar positions in a wall. On the other hand it must not be supposed that each sill or cap that is broken demon-

strates the unsuitable character of the stone thus used. Sills and caps may break on account of various other causes, among which are unequal settling of the wall and improper laying of the stone.

Many building stones, that are perfectly suited to withstand the compressive stresses in the body of a wall, have such a low modulus of rupture as to be unfit for use in position where a high transverse strength is necessary. In order to escape possible dangers from this direction, it is customary, especially in the heavier buildings, to arch the doors and windows. By this method the load is distributed, and the danger of rupture, through unequal stresses or inherent weakness of the stone, is largely avoided.

For the purpose of obtaining the transverse strength of the Wisconsin building stone, specimens having a cross section of approximately one inch, and a length of from 4 to 7 inches, were carefully prepared and measured in the laboratory of the University of Wisconsin. They were then broken in an Olson testing machine and the modulus of rupture computed from the following formula:

$$W = \frac{2\,b\,d^2}{3l}\,R, \text{ from which}$$

$$R = \frac{3l}{2\,b\,d^2}\,W.$$

W = concentrated load at center in pounds.
b = breadth in inches.
d = depth in inches.
l = length.
R = modulus of rupture in lbs. per sq. in.

The manner and place in which the specimens broke were each carefully recorded, and will be found in Part II., Chapter VIII., Table III.

Modulus of Elasticity—The modulus of elasticity is synonymous with coefficient of elasticity, and is sometimes defined as the weight that would be required to stretch a rod one square inch in section to double its length. It is generally expressed in pounds per square inch. It is "valuable in determining the

effect of combining masonry and metal, of joining different kinds of masonry, or of joining new masonry to old; in calculating the effect of loading a masonry arch; in proportioning abutments and piers of railroad bridges subject to shock, etc." (Baker.)

The modulus of elasticity was computed for a large number of the samples for which the crushing strength was obtained. In performing the crushing strength tests, the amount of compression for each increment of 500 to 1,000 pounds pressure was obtained by use of a compressiometer, and recorded up to the limit of elasticity, and from these data the modulus of elasticity was computed. The results recorded in the table are undoubtedly lower than they should be, on account of the insertion of thin strips of blotting paper between the bearing faces and the plates.

Durability Tests.

Specific Gravity.—The determination of the density or specific gravity, although not the most important, is probably the first durability test which should be performed. This is found by comparing the weight of the stone with the weight of an equal volume of water. A number of different methods have been employed to obtain this relation, the most common of which is probably that employed by Gen. Gilmore. He first weighed the samples in air, then immersed them in water, and, allowing all the bubbles to be given off, he weighed them suspended in water. Taking them out of the water, he dried them with blotting paper and weighed them again in air. Subtracting the weight in water from this last weight, he determined the specific gravity by dividing the weight of the dry stone by the difference. This method appears to be faulty in several particulars. First, to obtain the dry weight, samples of stone must be heated to a temperature of 110° C. At a lower temperature than this the interstitial water is not entirely driven off. Second, the correct weight of the samples in water can only be obtained after

they have been completely saturated. A sample is certainly not completely saturated by simply allowing it to remain in water until bubbling ceases. Third, the true difference is the difference in the weight of the dry sample (not the wet), weighed in air and the weight of the saturated sample suspended in water.

The method employed at Rose Polytechnic Institute,[1] is to weigh the sample in air and then in water as quickly as possible, and divide the weight in air by the loss of weight in water. This method is faulty, because the correct weight in air can only be had after all the interstitial water has been expelled. Further, the correct weight of the sample suspended in water can be obtained only after the sample has been completely saturated. A third method is that which is commonly known as the specific gravity bottle. By this method "a small bottle is weighed, filled with distilled water and weighed again. The bottle is then emptied, dried, the powdered stone put in, and reweighed. These weights give the weight of the stone and the weight of the bottle full of water. The bottle containing the sample is partly filled with water and suction applied to exhaust the air bubbles, the filling completed, and another weight taken."[2] The specific gravity is then computed by dividing the weight of the stone by the weight of the water displaced by the stone. By this method errors are more liable to creep in, through careless manipulation, than by other methods, but when sufficient care is exercised the method gives more nearly the required results than those previously outlined.

The determinations made in the laboratory of the University of Wisconsin, in preparation for this report, were obtained by a somewhat different method than any of the preceding. It was recognized that the true specific gravity of a rock can only be obtained by weighing the samples in air, at a definite temperature, after all the interstitial water has been expelled;

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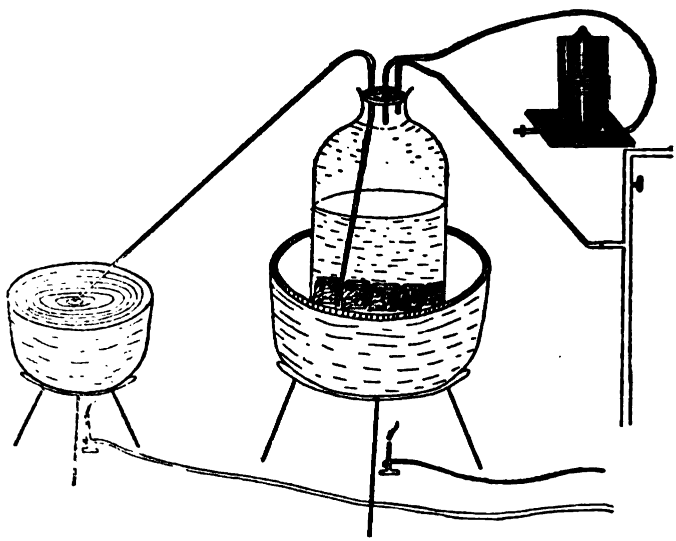
[1] The Building Materials of Pennsylvania; Brownstones: Appendix to the Annual Report of Penn. State College, 1896, p. 27, T. C. Hopkins.

[2] Ibid., p. 26.

then weighing them, completely saturated with water, in water; and finally dividing the weight in air by the difference. It is very true that these ideal conditions of absolute freedom from interstitial water in the one case, and complete saturation in the other, are difficult to obtain. But by sufficient care, it is thought that these conditions can be nearly attained. All the moisture cannot be driven off from the samples of stone by heating to a temperature of 100° C. Two inch cubes must be dried in a hot air bath at a temperature of 110° C. for twenty-four hours before the included water will be practically all expelled. It is not possible to completely saturate a sample by quickly immersing it in cold water. The water will pass into the sample from all directions and enclose small air bubbles, which can only be expelled with the greatest difficulty. If, as in the method employed in this report, the cubes are slowly immersed from the bottom to the top in boiling water, under the receiver of an air pump, in which the pressure is maintained for 72 hours at less than 1-10 of an atmosphere, the probability is that the samples will be saturated.

The samples used in making the determinations recorded in this report were cubical in shape, and weighed from 42 to 393 grains. The majority of the samples were two inch cubes similar to those used in making the other tests. The samples were carefully washed and cleaned and heated in a hot air bath to a uniform weight, at a temperature of 110° C. The weight was recorded in grammes to the second decimal place. The samples were then placed in a large bottle in which the cork was tightly sealed. (See Fig. 1, p. 66.) The bottle was then placed in a water bath which was kept at a temperature of 100° C. The air was exhausted from the bottle by means of an air pump, until the pressure within the bottle, as indicated by the manometer attachment, was reduced to at least a twelfth of an atmosphere. Under these conditions the bottle would become partly filled with water vapor which would make the amount of air in the bottle less than that recorded by the manometer. The density of the air contained within the pores of the samples would thus be the same as that within the bottle, or about 1-12

of what it would be under normal conditions. Under these conditions the replacement of the air by water, in the pores of the rock, would meet with less resistance than under ordinary conditions. In order to provide for the passage of water into the bottle a piece of glass tubing was inserted through the cork. A rubber tube, which extended to the bottom of the bottle, was attached to the inside end of the glass tube, and another, which was attached to the exterior end of the glass tube, terminated in a basin of distilled water heated to a temperature of 100° C.



APPARATUS DEVISED FOR SATURATING SAMPLES OF STONE.

FIG. 1.

A stop cock cut off communication between the interior of the bottle and the basin of water. Upon operating the stop cock and starting the air pump, it was possible to keep the pressure in the bottle nearly constant, and at the same time draw any desired amount of water into the bottle. In this manner water was slowly fed into the bottle until the samples were entirely immersed. By this process of slow feeding from the bottom, the water meets with the least possible resistance in ascending, and replacing the air, in the pores of the rock.

The above conditions are thought to be the most favorable

under which the samples could be successfully saturated. After allowing the samples to remain in the bottle under a pressure of about 1-12 of an atmosphere for 36 hours they were removed and weighed. These weights were recorded, and, in order to be certain that there would be no appreciable increase in absorption by continued soaking, the cubes, without drying, were returned to the empty bottle, which was again sealed and the process repeated. The samples were allowed to remain in the bottle under similar conditions as before, for another period of 36 hours, when they were weighed a second time and their weights recorded. A comparison of the two series of weights, as given in Part II., Chapter VIII., Table V., indicates that in most cases there was no very appreciable absorption during the last 36 hours' soaking.

To weigh the saturated samples they were placed in an earthenware vessel, immersed in distilled water, and thus transferred to the weighing room. After removing the samples from the basin, the film of water adhering to the surface was removed by means of bibulous paper, and the sample transferred to the scale pan, and quickly weighed. The samples, it is true, lost a small amount of water through evaporation, but not enough to alter the results appreciably. After the final weighing was made to determine the saturation, the samples were suspended by a silk thread in distilled water, and again weighed. These weights were recorded and the specimens transferred to a hot air bath, where they were again heated at a temperature of 110° C. to drive off the interstitial water. After heating at this temperature for about 24 hours, the samples were again weighed and the weights recorded for comparison with the first dry weights. In some cases the second dry weight was identical with the first to a hundredth of a gram. In but very few instances did the weights vary over 2-10 of a gram, which would be an error of only 1-800 to 1-1500 of the total weight, or 1-100 of the increase in weight. When reckoned in per cent., the error would be such a small fraction of 1 per cent. as not to be worthy of attention. The specific gravity was determined by dividing the average of

the two dry weights by the difference between the average dry weight and the weight of the cube suspended in water. The results are recorded in Part II., Chapter VIII., Table V.

Porosity.—The percentage of pore space in a rock is ordinarily known as its porosity. This is ordinarily determined by finding the percentage, which the amount of water absorbed by the sample bears to the total mass. But the weight of the water absorbed, compared with the weight of the dry sample, does not give the pore space. In order to obtain the volume relation, the weight of the absorbed water should be multiplied by the specific gravity of the rock, which computation naturally increases the result. Following the general law enunciated by Hunt, that "the value of a stone for building purposes is inversely as its porosity," it has apparently been the policy of those who have reported on building stones for their respective states, to avoid any computation which would apparently result in increasing the porosity of the building stone which they were testing. In another part of this report (cf. pp. 20–23), I have shown that the ratio of absorption or porosity does not indicate the value of the stone for building purposes, except when the more important factor of the *size* of the interspaces is taken into consideration. Besides being valuable in estimating the danger from freezng and thawing of the interstitial water, the porosity "affords an index to the various chemical actions of solution, oxidation, etc., since the chemical elements which produce these changes are mainly carried into the stone by the water absorbed."[1]

The method of obtaining the porosity ordinarily employed is as follows: The sample to be tested is heated at a temperature of 100° C. to drive off the moisture. After cooling, the sample is weighed, and then slowly immersed in distilled water. After bubbles cease to be given off the sample is removed from the water, and the surfaces quickly dried with bibulous paper, after which the specimen is again weighed. The difference in weight gives the increase due to the absorption of

[1] Iowa Building Stone, by H. F. Bain: Ann. Report of the Iowa Geological Survey. Vol. VIII., 1898, p. 405.

water. This difference divided by the weight of the dry stone is called the porosity, or ratio of absorption.

Several errors are apparent in the method outlined above. At 100° C. the interstitial water is not completely expelled. As was stated above, in order to expel the moisture from samples of stone, it is necessary that they be subjected to a temperature of 110° C. Further, samples of stone cannot be completely saturated "by immersing in distilled water until bubbles cease to be given off." Finally, as has been previously explained, the porosity or pore space can not be obtained by dividing the weight of the dry specimen by the increased weight due to absorption. By this method one obtains a result which had better be called the ratio of absorption, because it is not the porosity.

In obtaining the porosity of the samples tested in this report, the dry and saturated weights obtained for the samples used in computing the specific gravity, were used. The difference in these weights was multiplied by the specific gravity of the rock. This amount was added to the dry weight, giving the sum. The difference of the dry and saturated weights multiplied by the Sp. Gr. of the rock, was then divided by the sum. This last result is the actual percentage of pore space compared with the volume of the sample tested. The results obtained for all the samples tested will be found in Part II., Chapter VIII., Table V. The ratio of absorption computed by the ordinary method is given in another column of the same table for comparison. It is thought that the results here obtained are more nearly correct than those ordinarily given.

Weight of the Stone—Ordinarily the weight of stone, as it is taken from the quarry, depends upon its specific gravity, the amount of pore space, and the water content. The only fluctuating quantity for any particular stone is the water content. This will differ largely in the more porous rocks, depending upon the thoroughness with which the rock has been seasoned, and whether or not it has absorbed fresh water since being taken from the quarry. Any determinations of the weight per cubic foot of a stone, which include an indefinite quantity of in-

terstitial water are unsatisfactory. Weights thus obtained depend upon a number of conditions, a change in any one of which will give a different result. The only constant weight is that of the dry stone. This can only be obtained after one has the data used in computing the actual percentage of pore space or porosity.

In determining the weight per cubic foot of the different samples of stone tested in this report, the weight of a cubic foot of water was multiplied by the specific gravity of the stone, which gives the weight of a cubic foot of stone of the given specific gravity, provided there were no pore spaces. In order to obtain the actual weight there was deducted from this the weight of a quantity of stone, of the same Sp. Gr., equal in volume to the percentage of pore space in the stone. The result was the actual weight of the stone free from interstitial water. The weight per cubic foot of the different stones from Wisconsin quarries is given in Part II., Chapter VIII., Table V.

Freezing and Thawing.—It has been stated, in a previous chapter, that one of the active agents of rock disintegration, is the alternate freezing and thawing of the interstatial water. The results of this process are seen in every quarry and in many buildings. It is difficult, of course, to measure quantitatively these results as they occur in nature. All the forces of disintegration are acting in conjunction, and therefore the results of any one can not be determined with any degree of certainty.

In the laboratory, the effect of freezing and thawing can be determined with a nearer approach to accuracy than elsewhere. Here, as in previous experiments, it becomes necessary to exaggerate very largely the actual conditions. Stone, after being placed in a wall, is seldom thoroughly saturated with water, except in the basement near what is known as the "water line." For a number of years it has been a matter of dispute among engineers, as to whether a stone dam was permeable to water or not. It is, of course, permeable, but the fact that the amount of water appearing on the outer face of the dam was so small as to raise the question, indicates the slowness with which a wall, not immersed on all sides, absorbs

water. The question still remains as to whether or not the pores in such a wall are filled with the water which is leeching through. Rain, beating for several days against a wall, may doubtfully soak into the rock almost to the point of saturation, but then only in exceptional cases will the temperature conditions be such, that the water in the stone will freeze before it has been partially or wholly disssipated. In proportion as the interspaces are small and non-continuous, the longer will the water be retained in the pores of the rock, and the greater will be the danger from freezing. Cracks and crevices may be filled with water, and in exceptional cases the water may freeze, by the expansion of which the openings will be enlarged.

Two methods, known as the natural and artificial, have been employed to determine the effect of alternate freezing and thawing, on samples of building stone. The natural method is to soak the samples with water and alternately freeze and thaw them, a few or many times, at the convenience of the operator. The artificial method is to saturate the stone with a boiling solution of a soluble salt, such as sodium sulphate, and then allow it to dry. The salt crystallizes, as the water evaporates, producing stresses similar to those produced by freezing water. Luquer discusses this method in detail in an article in the Transactions of the American Society of Civil Engineers,[1] to which the reader is referred.

The artificial method was not given serious consideration in the preparation of the tests recorded in this report, in view of the fact that the samples could be saturated with water and frozen under conditons which are more nearly in accord with those which actually occur in nature.

For the purpose of testing the freezing capacity of stone from the Wisconsin quarries, one inch and two inch cubes were used. The tests were made during the winter months, when the temperature outdoors was almost uniformly below freezing. The clean samples were first carefully dried in a hot-air bath at a temperature of 110° C. and weighed. After being saturated in distilled water, they were removed to an

[1] Trans. Amer. Soc. C. E., Vol. XXXIII., 1895, p. 234–247.

outdoor window-sill, and allowed to freeze over night. The next morning they were brought inside, thawed out, and placed in warm distilled water to soak. In the evening they were again removed to the window-sill. This process was continued for 35 days, at which time they were again placed in the hot-air bath and dried. They were weighed a second time and the loss of weight was computed. (See Part II., Chapter VIII., Table VI.) The two inch cubes were finally tested in a crushing machine to determine their compressive strength. These results will be found in the same table. In Table VII., of the same chapter, the crushing strength is compared with other tests made on cubes of the same stone, which were not subjected to alternate freezing and thawing.

Extreme Heat.—In the larger cities one of the essential qualities of a good building stone is the capacity to withstand extreme heat. In the conflagrations from which many of our cities have suffered, stone, brick, and wooden structures have crumbled alike. Blocks of granite have been broken into a thousand pieces, brick walls have crumbled into shapeless masses, while iron beams and girders have been melted and twisted into all conceivable shapes.

Most building materials may be destroyed if subjected to a very high heat. Some are destroyed at a comparatively low temperature, while others are barely affected at a temperature above the melting point of copper, (1200° F.). Different building stones show a considerable difference in the capacity which they have to withstand high temperatures. Other things being equal, it appears that a rock having a uniform texture and simple mineralogical composition has the greatest capacity to withstand extreme heat. It is known that rocks are poor conductors of heat, and for this reason the outer shell of a block may be very highly heated while the interior remains comparatively cold. If, after heating, the rock be quickly cooled contraction of the outer shell takes place. The differential stresses occasioned thereby, ruptures the rock and the outer shell is thrown off. This process is often repeated, until the rock is entirely destroyed. As has been previously

stated (cf. p. 19), the extremes of temperature during 24 hours, in some of the arid western regions, have occasioned the throwing off of thousands of fragments of rock from the mountain sides, forming immense talus slopes. If this is the effect of changes in the diurnal temperature, one can readily imagine the effect produced on the walls of a stone building by the extreme heat of a conflagration. The disastrous effects are naturally very greatly intensified by the water which is thrown upon the building in an endeavor to extinguish the flames. If the fire occurs in the winter, the effect is still further intensified by the freezing of the water.

The danger from fire is being lessened each year, by reducing to a minimum the amount of inflammable material used in construction. Buildings are now constructed, which, in themselves, are essentially fire-proof. In the case of large business houses the structures may not be inflammable, but the interior is generally packed from basement to roof with inflammable materials, which in case of fire would make the structures roarng furnaces. Provided the walls are constructed of stone, which has a capacity to withstand high temperatures, not only will the loss to the building itself be less, but the spread of the fire may be more easily checked. It is therefore important that one should know something of the degree of heat that a stone will stand, without injury, before it is used in a place where conflagrations are one of the possibilities. Stone from certain of the Wisconsin quarries has passed through some very severe fires without serious injury. From these examples one can learn something of the capacity which the stone has to withstand extreme heat. But in lieu of any conflagration tests, the laboratory furnace provides an excellent substitute.

The temperature tests embodied in this report were performed by placing one and two inch cubes in a muffle furnace, and gradually increasing the temperature from 600° to 1500° F. The visible effects at temperatures between 600° and 1500°, as indicated by a standard pyrometer, were carefully noted. At a temperature of 1300° to 1500° F. the specimens

were removed from the furnace. Most of them were allowed to cool gradually while several were suddenly cooled by plunging them into cold water. The results of these tests are given in Part II., Chapter VIII., Table X.

Carbonic Acid Gas and Sulphurous Acid Fumes.—Limestone is the only rock which is materially affected by the action of these gases, which are manifest, mainly in the large cities, where enormous quantities of bituminous coal are consumed. Experiments were performed in the laboratory to ascertain the effect which these gases have on the different Wisconsin limestones and dolomites. The tests were made in about the usual way. Two large mouthed bottles were obtained and in the bottom were placed several smaller bottles containing water, to keep the atmosphere moist. The small samples, (1 to 1½ in. cubes), were heated to a uniform weight, at a temperature of 110° C., and weighed. They were then placed in the large mouthed bottles and the corks were carefully sealed. Through each of the corks were passed two small glass tubes, to the ends of which rubber tubing was attached. Washed carbon dioxide was then passed into one of the bottles, and washed sulphur dioxide into the other. After the bottles had been filled with carbon dioxide and sulphur dioxide, respectively, the tubing was closed by means of pinch-cocks. The carbon dioxide and sulphur dioxide were each renewed about twice a week through a period of six weeks. The samples were then removed, washed in cold distilled water, heated at 110° C., until all included water was driven off, and finally weighed. The difference in weight is recorded in Part II., Chapter VIII., Tables VIII. and IX. The general appearance of the specimens after the treatment is also given under the heading of remarks.

The tests on the samples of stone from the different Wisconsin quarries are discussed at length in Part II., Chapter VIII.

PART II.

Geological History of Wisconsin and Description of Areas and Quarries.

CHAPTER I.

A BRIEF GEOLOGICAL HISTORY OF WISCONSIN.

The first conception that we have of the North American continent is that it existed in the earliest time with essentially the same outline that it has today. During this primordial period of its existence the earth's crust was very greatly modified through orographic movements by which the rocks were profoundly metamorphosed and complexly folded. The forces of degradation began their work as soon as the land was above the sea, and rested only when the continent had been entirely or almost reduced to sea level. Accompanying the orographic movements and contemporaneous with the period of denudation, molten material was intruded into the rocks or extruded from the surface, complicating and modifying the original and secondary structures. These rocks have been cut by the eruptive and intrusive rocks of all the later ages in a most complicated manner. The earliest rocks of which we have any knowledge are known as the Archean or Basement Complex. None of the rocks in the Archean are of known sedimentary origin. They consist mainly of banded and schistose rocks belonging to the metamorphic series of schists and gneisses. They are intensely folded and fractured, and for these reasons are, almost without exception, undesirable for either ornamental or building purposes.

After the North American continent had for the first time been base leveled and covered with the waters of the ocean, it is conceived by some that northern Wisconsin still remained above the sea, either as an isolated island or as a group of as-

sociated islands. It is possible that this was not the condition, but that Wisconsin was entirely submerged. The water which surrounded the islands of north central Wisconsin at that time, is known as the Lower Huronian sea. On the bottom of this sea there were deposited thousands of feet of sediments consisting mainly of pebbles, sand, and calcium carbonate. These were later changed into conglomerate, sandstone, and limestone. At the close of the Lower Huronian period the land was lifted above the sea, the rocks were folded and highly metamorphosed, and lava either flowed out from fissures at the surface of the earth or was pushed up between the beds of sediment, forming sills, dikes, and bosses. The sandstone was changed to quartzite, the limestone was transformed into finely crystalline marble, and many of the earlier igneous rocks were highly metamorphosed. Finally the land was wasted away by the atmospheric agencies, and again we find the ocean encroaching and covering the land. This closed the Lower Huronian period.

Upon the eroded, upturned, and folded strata of the Lower Huronian, great thicknesses of sediments were again laid down. This period is known as the Upper Huronian. These sediments consisted of pebbles, sand, and mud, all of which were later changed into shale, sandstone, and conglomerate. Finally, due to the accumulation of sediments or elevation of the land the ocean retreated a second time, and Wisconsin was again above the sea. The rocks were a third time folded and metamorphosed by the mountain making forces. Igneous material was pushed out at the surface or was intruded into the sediments of this and the older series. After many centuries of time the sea again encroached upon the land, and the remnants of the Lower and Upper Huronian series were buried beneath the waters of a new sea, known as the Keweenawan.

The Keweenawan period began with an immense outpouring of basic lava, which forms what is now known as the basal gabbro of this series. Following these conditions the land was alternately above and below the sea, as is shown by the interbedded sandstone, conglomerate, and lava. The closing stages of the period were marked by a quiescence in volcanic

activity and the accumulation of great thicknesses of sandstone and conglomerate. The land was finally raised above the sea, and the rocks were folded and metamorphosed by the orogenic forces. This time the forces were apparently weaker and the folding was consequently much simpler. The atmospheric agents began their work as soon as the land rose above the sea, and the continent was again wasted away until there remained only remnants of the immense beds of sandstone, conglomerate, and lava. Between the laying down of the Upper, and Lower Huronian series, and between the Upper Huronian and the Keweenawan there were time intervals of very considerable, but unknown, duration. The Upper and Lower Huronian series are distinct formations in many parts of the Lake Superior region but they have not been differentiated in Wisconsin, except in isolated places where detailed geological study has been pursued. The rocks of the Huronian series are the main source of supply for Wisconsin granite and quartzite. The exact extent of the Huronian rocks in Wisconsin has not been determined. The early maps were constructed from limited data at a time when field work was much more difficult than today, and are necessarily faulty in many ways. Late study of the northern crystalline area has shown that much which has been included in the Archean is really Huronian. Besides constituting the larger part of the northern crystalline area, the Huronian rocks outcrop locally at various places in the central and southern parts of the state. These isolated outcrops, as well as the more extended northern distribution, are not indicated on the general map, on account of their uncertain delimitation from the Archean. (See Map, Plate I.) The Upper and Lower Huronian rocks differ mainly in their degree of metamorphism, the lower series being more highly metamorphosed than the upper. The lower series has also been cut, not only by the igneous rocks of that epoch, but also by those of the two following epochs. The sedimentary rocks of both series are in many instances so completely changed, as to be distinguished form the associated eruptives only with the utmost difficulty. The igneous rocks are many of them very much

altered, while others are comparatively fresh. Among these rocks, all kinds may be found, from granite to gabbro, and from rhyolite to basalt. The Huronian rocks of the northern crystalline area constitute an enormous undeveloped wealth of the best kind of building and ornamental stone.

The Keweenawan series of Wisconsin is confined to the northwestern portion of the state, extending on the east into Michigan, and on the west and north into Minnesota. It rests unconformably above the Upper Huronian and unconformably below the Cambrian. The rocks of this series have never been used very largely either for building or ornamental purposes. The igneous rocks are very largely gabbro and diabase, and are undesirable for most economic purposes. The sandstone and conglomerate are as a rule too much metamorphosed to be suitable for quarrying.

With the wasting away of the land at the close of the Keweenawan, that portion of the continent immediately north of Wisconsin is supposed to have been depressed into what is known as the Lake Superior syncline. When the waters of the ocean again encroached upon the land, and the deposition of the Cambrian sedimentaries began, Wisconsin had ceased to be a center of volcanic activity and mountain building, and passed into a condition of comparative quiescence. The sedimentaries which have been laid down since Keweenawan time are horizontal, making it comparatively easy to separate the Cambrian and later sedimentaries, from those of the pre-Cambrian era. The Cambrian sea undoubtedly covered all parts of Wisconsin, with the possible exception of one or two of the more elevated portions to the north. The sea was shallow and the sediments consisted mainly of sand. As a result, the predominant rock is sandstone. The bed of the ocean probably subsided as the sediments were deposited, until the deposits reached a thickness of a thousand feet. Between the beds of sandstone, thin beds of shale occasionally occur, which indicate deeper water or quieter conditions. Some of the beds of sandstone likewise contain a considerable percentage of calcium carbonate or iron oxide, showing that the conditions of

deposition varied at different times and in different places. Only the closing epoch of the Cambrian, known as the Upper Cambrian, is represented in Wisconsin. The Upper Cambrian is known in this state as the Potsdam sandstone. The Cambrian sediments lie unconformably above the earlier pre-Cambrian rocks, and dip beneath the later Silurian. At the present time they have a large surficial extent in Wisconsin, both in the northern and the southern parts. They almost surround the north central crystalline area of the state, and are frequently found as outliers within the crystalline area itself. The color of the sandstone is mainly white or yellow, but north of the crystalline area and adjacent to Lake Superior, the stone is red or brown. A large part of the sandstone of the southern area is incoherent and poorly cemented, but that of the Lake Superior region is generally well cemented and consolidated. In the southern area the texture and hardness of the rock vary greatly. As a rule the sandstone is so soft as to crumble in the hands, but in certain places it is so hard as to almost pass for a quartzite. Again, it may be very coarse or very fine grained. If fine grained, it may be of a calcareous nature, furnishing a very desirable stone for constructional purposes. If coarse grained it is usually siliceous and of a crumbly or refractory nature. It could hardly be expected that the sediments at various horizons would be the same, or that the stone over such a large area would not vary greatly.

With the beginning of Cambrian time we have the first evidence of the appearance of life in Wisconsin. The rocks of the Cambrian contain numerous fossils of the lower forms of animal life. They are not the first or the lowest form of life that have existed on the earth, but they are the first that we have evidence of in Wisconsin.

At the close of the Cambrian period new conditions were initiated, and deeper sea deposits formed, in the shape of limestone. This epoch in the history of the Wisconsin formations is known as the Lower Magnesian, which is the beginning of the period known as the Ordovician or Lower Silurian. The limestone of this formation is dolomitic and in many places

filled with small irregular cavities, on account of which it is often called "hackly" limestone. The thickness of the Lower Magnesian is variously estimated at from 50 to 250 feet. The upper surface of this formation is very irregular, having the appearance, in many places, of ocean billows. The domes thus formed often rise as much as 25 or even 50 feet above the general level of the formation.

The rock of this formation which is hackly, does not furnish a desirable building stone. Its rough, cavernous character and the difficulty with which it is dressed has kept it from the market, except for the roughest work. The limestone of this formation which is quarried from the bluffs along the Mississippi river, has a much more uniform texture than that found elsewhere and is suitable for much finer constructional work.

The outcrops of Lower Magnesian limestone fringe the Potsdam sandstone area on the east from the Menominee river, the boundary between Michigan and Wisconsin, on the north, to Rock county on the south. In the southwestern part of the state the limestone caps many of the sandstone hills, reaching south along the Mississippi as far as the boundary line. It extends to the north along the Mississippi and St. Croix rivers as far as Polk county. Its distribution is very irregular, and can be best understood by a reference to the map. (See Pl. I.)

The Lower Magnesian Limestone epoch was followed by a shallow sea in which was deposited the St. Peter's sandstone. This sandstone is a soft incoherent rock which can usually be crumbled between the fingers. In places, it passes into a somewhat compacted stone, the particles of which are wholly or partially cemented together by iron oxide or silica. This formation has a much less surficial distribution than either of the preceding sedimentary formations. The sandstone may be traced, as was the Lower Magnesian limestone, from northeastern Wisconsin near the Michigan line as far south as the Illinois boundary. From thence it swings north along the Mississippi river region as far as Vernon county. The irregular distribution can best be understood by a reference to the map. (See

Pl. I.) The thickness differs in various parts of the state, averaging about 100 feet.

After the St. Peter's sandstone was laid down the conditions of deposition changed from a shallow to a deep sea. On the bottom of this deeper sea were deposited the sediments which comprise the Trenton and Galena limestone formations. The St. Peter's sandstone preserved but scanty remains of the life of that time, but in the Trenton rock there are the remains of an abundant fauna. So abundant were the marine animals living in the Trenton sea that certain of the beds of these formations are essentially composed of their shell remains.

During the formation of the Trenton limestone the conditions of deposition changed many times, as is shown by the thin interstratified layers of shale, which split the larger beds of limestone into relatively thin laminæ. Often the interlaminated shale is scarcely noticeable, but at other places it is very conspicuous. The laminæ of shale are generally discontinuous, being broken up into thin wavy leaves. The rock occasionally contains cavities filled or partly filled with calcite, pyrite, or marcasite. Certain of the upper beds of the Galena are very finely crystalline and dense, breaking occasionally with a splintery or conchoidal fracture, much after the fashion of glass. The Trenton beds differ in color, some being buff and others blue. Depending on these colors there has been differentiated what are known as the Upper and Lower Buff beds and the Upper and Lower Blue beds. These subdivisions are very arbitrary, being dependent almost entirely upon the extent to which the rock has weathered.

The Trenton has a large superficial extent in Wisconsin. Along the eastern half of the state it is found as far north as Marinette, from which point it extends south in a broad belt from ten to thirty miles wide as far as the Illinois line. It outcrops as far east as the western tier of townships of Walworth and Waukesha counties, from which place it extends to the west in a broad belt, passing beyond the Mississippi river into the adjacent states. In the west central portion of the

state, in St. Croix and Pierce counties, small outliers of Trenton limestone are found capping the higher hills. Everywhere this formation underlies the Niagara limestone and rests upon the St. Peter's sandstone.

After the Trenton and Galena limestone formations were deposited, the conditions were those of a shallow sea, and there was deposited the formation known as the Hudson River Shale. This formation did not result, in Wisconsin, in the formation of any desirable building stone. It is represented mainly by a soft, easily disintegrated shale, and a few rough beds of limestone. The surficial distribution is very limited. The formation outcrops in a narrow belt from one to six miles wide, extending from Sturgeon Bay, on the north, along the eastern border of Green Bay and Lake Winnebago, in a southerly direction to the Illinois boundary line, near the middle of Walworth county .

After the deposition of the Hudson River Shale the land is supposed to have been, at least, partially elevated above the ocean. The following was a period of very low, stagnant water, during which there was deposited a thin bed of iron ore, known as the Clinton formation. The appearance of these beds of iron ore at this place is an indication of low, swampy conditions. The surficial extent of these beds is very limited. They fringe the Hudson river shale in a very narrow belt and pass quickly under the Niagara limestone to the east.

Following the erosion interval marked by the Clinton iron ore beds, there began another period of relatively deep sea conditions, during which the Niagara limestone was deposited. The thickness of the limestone varies from 450 feet in the southern part of the state to 800 feet in the east central part. Fossils are generally abundant, trilobites and coral remains being especially numerous in certain beds. The character of the beds differs quite widely in different portions of the state. In certain places the limestone is uniform in color and texture, while in other places there are many irregularities both in texture and color. From many of the beds very excellent stone can be obtained, but from others the stone has such an

irregular texture as to be of little value for constructional work.

The Silurian period closed in Wisconsin with the deposit of a light gray, magnesian limestone, constituting what is known as the Lower Heldeberg formation. The rocks, which are thus doubtfully classified, occur in a few small areas in Milwaukee and Ozaukee counties.

Following the deposition of the sediments, of which the Niagara and Lower Heldeberg limestone are composed, the ocean retreated from Wisconsin, to return for the last time during the Devonian epoch, when it deposited the Hamilton limestone. The only outcrops of this formation are found in the vicinity of Milwaukee. The formation does not contribute anything to the building stone of the state, but the stone is quarried quite extensively for the manufacture of cement.

Since the Devonian sea receded from Wisconsin, it is thought that the waters of the ocean have never, with possibly one exception, encroached far enough north to cover Wisconsin. Wisconsin has probably been a portion of the continental land area continuously from that time to the present.

Since the earliest time forces have been operating which have produced wonderful changes in the mineralogical composition and structure of the rocks. By the agents of metamorphism, rocks originally weak and incoherent, have been firmly consolidated. Rocks that were originally uncemented have been cemented. One mineral has been changed into another; minerals have replaced one another; amorphous substances have become crystalline; and portions of the rock have been entirely dissolved and carried away by underground water, forming cavities and even caves or caverns. These cavities and caves have in many instances been later partially or entirely refilled with other minerals, such as calcite, pyrite, marcasite, or quartz.

The rocks have all suffered more or less from mechanical deformation. The more ancient have been folded and fractured, and their individual particles are often so mashed as to almost if not entirely obscure their origin. The younger

rocks from the Cambrian to the present time have been gently folded, jointed, and faulted. The folding is very gentle and only noticeable when observations are made over extended areas. The jointing is simple, although the fracture planes are often very numerous in one or two directions.

The configuration of the surface of the state has been modified since the sea receded, both by running water and moving ice. The glaciers have in many places removed the soil and loose fragments of rock, increasing the accessibility of the fresh stone. In other places the glaciers have buried the rock under many feet of till or boulder clay, making it practically inaccessible. In the terminal morainal and over-wash areas the underlying rock is sometimes buried to a depth of 300 or 400 feet by glacial drift, while in the areas back from the moraines the till often barely conceals the underlying rock. In some sections of the state the glaciers have brought to the surface the comparatively fresh rock, which, previously, was buried to a considerable depth by disintegration. The glaciers powdered the rock which was worn away, and the waters formed by the melting of the ice, assorted and deposited it, forming the beds of clay and kaolin, which, through artificial processes, are recemented and placed upon the market in competition with stone.

Before the glacial epoch, the rivers of Wisconsin cut deep channels through the rocks on their way to the ocean. The deposits left by the glaciers often fill the valleys, and in some places have changed the course of the rivers. In other places the present rivers flow in their old channels, working over the deposits left by the retreating ice. Wherever the rivers have cut their channels to any considerable depth, there the rocks are exposed on either side. For example, along the Mississippi river, the high bluffs at Trempealeau, La Crosse, Maiden Rock, and other places, are formed by the erosion of the Mississippi river and its tributaries. The rocks are exposed in thousands of places along the sides of ravines, where mere threads of rivers have cut their way.

The rocks are a thousand times more accessible because of the existence of the rivers, although they have but scarcely begun

to obliterate the evidences of the last glacial epoch. The rounded forms of topography still remain almost as perfect as the day they were formed. Millions of boulders brought by the glaciers from the north, are strewn over the surface of the ground. Many of them are beautiful granites, which might furnish no insignificant contribution to the building stone wealth of the state.

CHAPTER II.

IGNEOUS AND METAMORPHIC ROCKS.

I. THE IGNEOUS ROCKS.

The many kinds of igneous rocks in Wisconsin are all of Pre-Cambrian age. Among the more abundant may be mentioned granite, rhyolite, diabase, gabbro, and diorite. These rocks occur in varying abundance among the Archean, Huronian, and Keweenawan series. Because of the abundance of igneous rocks in the north central part of the state, this region is often spoken of as the great north central crystalline area of Wisconsin. Approximately 21,000 square miles, or about one-third of the total surficial area of Wisconsin is immediately underlain by these rocks. The crystalline area is hemmed in on the east, south, and north by the overlying Potsdam sandstone, and passes to the northeast into Michigan, and to the northwest into Minnesota. To the south, the rivers flowing out of this region have, in many instances, cut their channels through the soft sandstone above, into the igneous rocks below, exposing them for 40 or 50 miles south of the main area. As a result of unequal erosion, small knobs of igneous rocks are found protruding through the later sedimentaries in the southern and central parts of the state.

The value of the many varieties and the abundance of the igneous rocks that can be profitably quarried cannot yet be estimated. Comparatively few quarries have thus far been opened, and especially in the main area few attempts have been made to utilize the granite which there occurs, either for building or monumental purposes. The first granite quarry in Wis-

consin was opened by L. S. Cohn at Granite Heights in 1880. Nearly contemporaneous with the opening of this quarry, the granite industry at Montello was started. These quarries may be called the pioneers in the development of the Wisconsin granite industry. Since that time, as near as can be ascertained, seventeen different granite quarries have been opened in this state.

The promoters of the granite industry have experienced the same difficulties in this state that are met by the operators of new quarries in all parts of the country. The stone which they were introducing in the market had no reputation; it had never been used; the stone had not been tested; the only recommendation which it had, was the reputation of the operator and the general appearance of the product. The early operators frequently had very little capital to invest; the facilities at hand for quarrying were in some cases of the most meager kind; and it is not surprising that companies have failed, and that men have lost money in the development of this new industry. Of the larger concerns that have met with reverses, not one has been occasioned by an inferior quality of stone or by a lack of demand. Failure has rather been due to the general business depression and to incompetent management.

The igneous rocks which are quarried in this state are mainly granite and rhyolite. The purposes for which these stones are quarried are mainly monumental, building, and road construction. Certain of the quarries can furnish granite of any desired dimensions and of unquestionable quality for heavy constructional purposes. In other quarries the possible dimensions of the quarried stone are such that its use is limited to the smaller constructional purposes, monumental work, and road making. The quarries of Wisconsin now furnish thirteen different colored and textured granites. Among these there are all colors from brilliant red to dark gray; and all textures from exceedingly fine grained to the most coarsely porphyritic.

For monumental purposes the granites of Wisconsin have been selected by competent judges in preference to granites from any other part of the United States, and, in one conspicu-

ous instance, in preference to the granites of three other competing continents. In point of color, durability, and finish they have no superior.

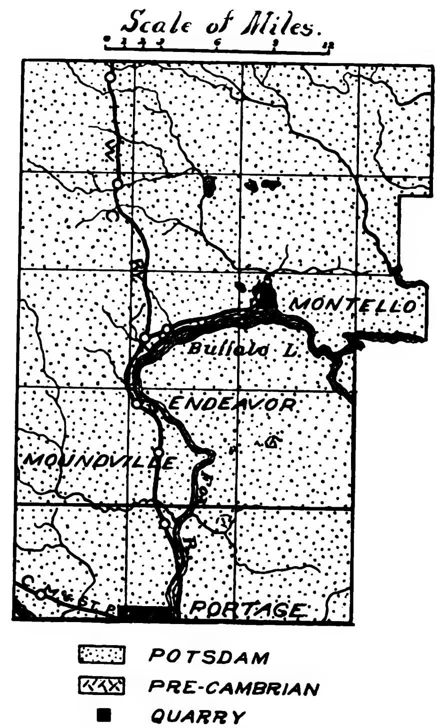
For constructional purposes the Wisconsin quarries can furnish either gray or red granite of any required dimensions. The facilities which certain of the companies possess, for quarrying and handling the granite used in heavy constructional work, are not surpassed anywhere else in the Northwest. For inside ornamental purposes the granites from Wisconsin compare favorably both in variety and color with those of neighboring states. For road construction probably no state in the union is better provided with material, in the shape of granite and rhyolite, than Wisconsin. Besides the north central crystalline area, the small knobs of porphyry and granite, which rise above the soft sandstone rocks of central Wisconsin, furnish a wealth of material which is unsurpassed for road construction.

The following are the areas from which granite and rhyolite have been quarried during the last few years: Montello, Berlin, Waushara, Utley, Marquette, Granite City, Waupaca, Wausau, and Amberg. Other areas which have been opened up, but are as yet undeveloped, are High Bridge, Irma, Prairie River, and Endeavor.

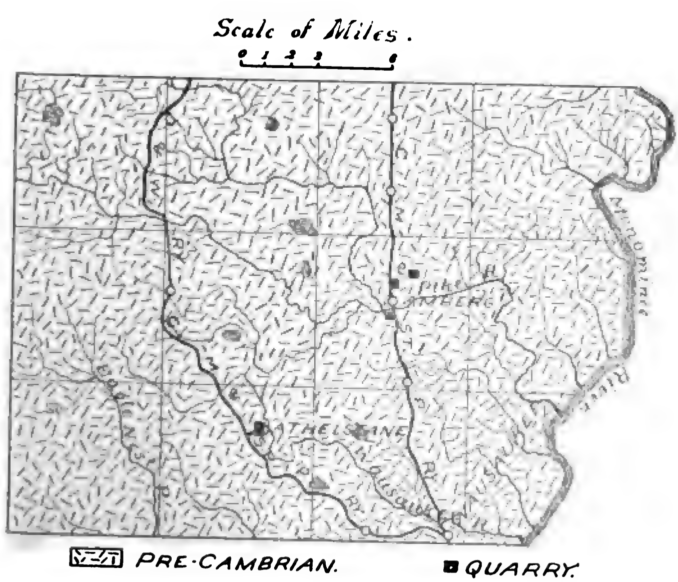
Description of Individual Areas.

MONTELLO AREA.

The Montello granite is obtained from two of the many isolated mounds of igneous rock located a short distance south of the main crystalline area. The granite mounds at Montello are situated near the central part of Marquette county on Secs. 8 and 9, T. 15, R. 10 E. The larger mound extends in an almost east and west direction for about a third of a mile, and rises in the highest part about 80 or 90 feet above the general level of the adjacent country. The smaller mound is east of the large one and is separated from it by a low saddle. It is a much less conspicuous feature of the landscape and has furnished less



MONTELLO AREA.



AMBERG AREA.

stone for the market. The mounds are largely covered with a thin mantle of glacial debris, which fortunately is not of sufficient thickness to materially increase the expense of working. The quantity of stone available may be said to be practically unlimited. Until 1897 the only company actively engaged in quarrying at this place was the Berlin-Montello Granite Co., which, since the reorganization in 1898, has been known as the Montello Granite Co. Last year a new firm was organized which is known as the Merkle Granite Co.

THE MONTELLO GRANITE CO.

The Montello Granite Co.'s quarry was opened about 1880, and has been operated continuously ever since. Several years ago, at the time of the general business depression, the company owning and operating the works became financially involved. The quarry and works passed into the hands of a receiver, and for the first time they were closed. The period of litigation passed, and the quarry and works were sold to a new company, known as the Montello Granite Co. Operations have been resumed and the company are now in a position to furnish estimates on all classes of granite work. During the period of litigation of the Berlin-Montello Granite Co., the Merkle Granite Co. was organized, and in a short time they had built up a flourishing monumental business.

The Montello Granite Co. controls about 80 acres of land, including the most accessible portions of the larger granite knob. The quarrying operations have been carried on at two different openings, one at each of the two mounds. The larger opening and the one most extensively operated is situated at the west end of the larger mound and within the limits of the city of Montello. (See Pl. IV., Fig. 2.) The second and much smaller opening is about ¾ of a mile east of the first, and is located on the top of the smaller mound.

Quarry Observations.

The main opening of the quarry, situated at the west end of the hill and adjacent to the company works, is about 200 feet

long, 150 feet wide, and 80–90 feet deep. The stripping is very light, having a maximum thickness of 6–12 feet at the east end. The granite is naturally exposed over a portion of the hill south of the main opening. From this part, which is adjacent to the main opening, a small amount of stock has been quarried. The surface of the exposed portions, where the soil has been lately removed, is very smooth. Where indications show that the rock has been exposed for a very long time, the surface is a very little rough. The color of the weathered surface is a grayish white, occasioned, here as elsewhere, by the bleaching due to direct exposure to the weather. This discoloration does not penetrate the rock to any perceptible depth, being the merest film upon the surface. Lichens grow quite abundantly on the natural exposures, bearing evidence of durability.

Three prominent sets of joints were observed in the quarry, striking N. 85° E., N. 25° E., and N. 40° W. The first two sets are vertical, and the latter dips at an angle of 82°. The floor of the quarry is uneven, dipping at various angles and in different directions. The main part dips at an angle of 14° NE. Besides the major joints, the granite is broken up by many short, discontinuous parting planes, striking in different directions. These jointing planes break the rock into various sized polygonal blocks, ranging from pieces a foot in the largest dimension to those that are 14 feet by 5 feet by 2 feet. Large dimensions are not the rule, but blocks of any reasonable size can be obtained.

The quarry face is cut by five large greenstone dikes, which apparently follow the jointing planes. The largest dike, about 4 feet wide, forms the north wall of the quarry opening. Some of the dikes strike N. 85° E., and others N. 25° E., these being the directions of the two main sets of joints. The greenstone magma has filled many of the smaller seams, adjacent to the larger dikes, injuring such stone for monumental purposes.

The work on the smaller mound to the east was begun and vigorously pushed when the demand for paving blocks was at its height, but no stone has been quarried at this mound for several years past. The opening is of irregular shape, 50 feet

long, 40 feet wide, and 20 feet deep. The rock is practically free from soil or clay covering for a considerable distance about the opening, offering an excellent opportunity to study the rock in the natural exposure. The color of the weathered surface is grayish white, the same as in the previously described opening. Lichens are abundant. The main sets of joints strike respectively N. 85° E., and N. 20°–25° E. Other, nearly horizontal joints, but dipping at different angles and in different directions, form the floor of the quarry. The two sets of joints first mentioned are often very close together, rendering a part of the rock unsuitable for large dimensional purposes. The blocks thus formed are often not over 8 or 10 inches in cross section. This close jointing apparently traverses the quarry in zones. Between these zones, the joints are much farther apart permitting the quarrying of blocks of fairly large dimension.

The granite, as a whole, is a dense, fine grained rock, uniform throughout the quarry. The color is red, two distinct tints being quarried from the larger opening. One is a cheerful red, while the other has more of a grayish red color. No regularity in the occurrence of the two different tints could be made out, although it was ascertained that in certain instances they grade into each other. The granite is stained along the joints with yellowish brown iron oxide. Black and white streaks traverse the rock in various directions, occasionally becoming a source of considerable annoyance. These dark streaks have been mentioned before as resulting from the greenstone magma, which found its way along the fracture planes at the time the greenstone dikes were formed. The white streaks are small veins of secondary quartz, probably of later origin than the dikes of greenstone. These veins are not especially injurious to the life of the granite, but where present, they mar the uniformity of color, which is one of the essential qualities of No. 1 monumental stone.

The best stock in sight is at the north end of the face, which strikes north and south. At that place quarrying operations can extend no farther on account of having reached the public highway, and beyond which the land is church property.

Sooner or later the public highway must be abandoned and the church property sold, in order to permit the development of the industry, which is the mainstay of the city.

Laboratory Examination.

The Dressed Sample.—The examination of a dressed and polished specimen, such as may be seen in the laboratory of the Survey, shows that the rock is suitable for the finest kind of finished work. As a rule, the granite does not break with a rough or conchoidal fracture, but generally evenly and smoothly, furnishing a rock face which is not bold, but rather subdued and quiet. As one would naturally suppose, the hammered work on a rock of this texture is very excellent, furnishing an exceedingly smooth, uniform surface. The color of the hammered surface is white, with a delicate tinge of red, being much lighter than either the polished surface or the rock face. The polished surface of the granite is almost perfect, the color being much livelier than that of the rock face. A close, detailed examination of the surface shows irregular areas of dark and light red, irregularly dotted with small black particles, having a metallic sheen. At a very short distance, these tints are so harmoniously blended as to give a very pleasing red color, different from that of almost any other granite. Indeed, the stone is one of exceptional beauty, being unsurpassed in this quality by any foreign stone. The color of the polished surface and the grain of the rock are nicely shown in the accompanying plate. (Pl. VI., Fig. 1.)

Microscopical Examination.—The thin sections of the granite, examined under the microscope, reveal definitely its mineralogical composition and texture.

The granite has a holocrystalline, granitic texture. Orthoclase feldspar and quartz are the preponderant constituents, and magnetite, chlorite, fibrous hornblende, hematite, and calcite are the subordinate constituents. One-half or more of the rock is composed of feldspar, while more than four-fifths of the remainder is quartz. The large irregular quartz and feldspar

QUARRIES AT MONTELLO.

1. Merkle Granite Co.

2. Montello Granite Co.

individuals are often separated from each other by a mosaic of finely crystalline quartz and feldspar, the grains of which interlock in such a complicated fashion as to give a very compact structure. Often the quartz and feldspar have formed such an intimate intergrowth as to produce the texture known as micro-pegmatitic. Peripheral granulation is characteristic of many of the larger individuals, while they all exhibit a marked undulatory extinction. The undulatory extinction or strain effects are more pronounced in the quartz than in the feldspar.

Much of the feldspar has the appearance of the variety known as microcline, while other sections are certainly orthoclase. Many of the feldspars have been twinned, giving the appearance on the surface of having been etched. The feldspars are generally very fresh looking, although many of them have been stained, along the cleavage planes, with red iron oxide.

Magnetite is present in small irregular patches and granules, some of which is partially altered to hematite. Associated with the hematite are the green minerals, chlorite, and hornblende, neither of which is of any considerable importance, as a constituent of the granite. It is the hematite which occurs along the cleavage planes of the feldspar, and about the margins of the individual grains, that gives depth and brilliancy to the red color of the rock. A dull tint indicates a less percentage of hematite than a bright. Two or three small flecks of sericite or muscovite were observed in one of these sections.

The above examination of the Montello granite clearly indicates that the mineralogical composition is such as to give to the rock very great strength and permanence. The small size of the individual minerals and the manner in which they interlock, contribute largely to the durability of the rock. (See Pl. LXI., Fig. 1.)

Chemical Analysis.—The high percentages of silica and alumina and the freedom from impurities, shown by the chemical analysis, substantiate the results of the microscopical examination, being indicative of the durability of the rock.

The chemical composition of the Montello granite, as determined by Ferdinand G. Weichmann,[1] is as follows:

SiO_2	75.40
Al_2O_3	11.34
Fe_2O_3	4.16
CaO	.90
K_2O	6.44
Na_2O	1.76
	100.00

Physical Tests.—The physical examination of the Montello granite gives additional testimony to its durability. It will be found by referring to Chapter VIII., Table V., that the specific gravity of the granite is 2.64, which is the same as the rhyolite of Berlin and the granite of Waushara county. The average porosity is the same as that of the Berlin rhyolite, being 0.21 of 1 per cent. The average amount of water absorbed by a two inch cube after 76 hours of soaking was only .35 of a gram.

Cubes were subjected to extreme heat, and not until a temperature of 1300°–1500° F. had been reached were the samples destroyed. Upon heating, the color became much lighter, and cracks opened near the middle of the cubes. At a temperature below 1000° F. it is thought that the granite will remain free from any considerable injury.

Alternate freezing and thawing, as shown in Chapter VIII., Table VII., resulted in an average loss in weight of only .045 of a gram on a mass weighing about 375 grams. This is a scarcely appreciable amount, and might easily be accounted for by errors in manipulation. The strength of the stone, as indicated by the same table, showed the effect of freezing and thawing more than the weight. The average crushing strength of the frozen samples was 3,199 lbs. per square inch lower than that of fresh cubes. (See Chapter VIII., Table VII.) This result is not absolute, but will vary between quite wide limits. Perhaps nearly as much as the difference given in this instance.

[1]Science, New Series, Vol. VI., No 147, pp. 621-622.

MONTELLO GRANITE.

Monument in the National Park, Gettysburg, Pa.

The compressive and transverse strength tests show that the Montello granite is exceptionally strong. The compressive strength tests show a maximum ultimate strength of 43,973 lbs. per square inch on two inch cubes. The transverse strength tests show an average modulus of rupture of 3,793.8 lbs. per square inch. Both of these tests are far above the average for granite. The compressive strength per square inch is higher than that of any previously published tests on granite. No true granite on this continent is known, that will equal the Montello in crushing strength, although even this strength has been surpassed by a rhyolite from our own state.

General Considerations.

In general, the tests have proven that for durability and strength there are few granites that anywhere equal the Montello. The qualities which contribute to its durability and strength, make it an exceedingly difficult stone to cut and dress. The price of the Montello granite is therefore higher than that of stone which is more easily worked; but where durability and strength are of prime importance, the stone is worth all the additional expense of cutting and polishing. Its qualities are so enduring that it will be found standing in many of our cemeteries uninjured long after the monuments and mausoleums constructed out of most kinds of stone have crumbled into decay.

The blocks which are too small or unsuitable for building or monumental work are crushed for macadam. The rip-rap which often accumulates in a quarry has been thus used to advantage. During the years when the demand for granite blocks for paving was at its height, many thousands were made at the quarry and sold in Milwaukee and Chicago. For both macadam and paving the granite has proven its suitability. But, on account of the difficulty in working the granite for paving blocks, combined with a falling off in the demand, this field has been largely abandoned. The use of crushed granite for macadam is apparently on the increase and the prospects for a large demand from this source are very favorable.

The Montello granite can, to all appearances, be most profitably worked where the monumental, building, and macadam enterprises are combined. The stone is well suited to all three purposes, and should find a large sale where strength and durability are the essential factors.

Some of the finest monuments of the country have been constructed from the Montello granite. They may be found by the score in the cemeteries of Illinois, Indiana, Ohio, Pennsylvania, Michigan, Iowa, and Wisconsin. Among the more important pieces of work may be mentioned the Custer monument and the monuments to Wisconsin soldiers at Gettysburg and Chickamauga. The sarcophagi for General and Mrs. U. S. Grant at Riverside Park, New York, were hewn from Montello granite, having been selected by a special commission in competition with granites from many parts of the world. These sarcophagi were cut from single large blocks measuring approximately 10 ft. 6 in., by 5 ft. 6 in., by 4 ft. 10 in.

But the Montello granite has not been used solely for monumental purposes and road construction. It constitutes a part of the superstructure of many important buildings. In Chicago it has been used in the Herald building, 158–160 Washington St., the Stone Building, West Madison and Ashland Ave., the Pickard residence, Burton Place and Dearborn Ave., the Miller residence, Walton Place and Lake Shore Drive, the Kirk block, Madison Ave. and 55th St., and many others.

The works of the Montello Granite Co. are well equipped for doing a large business. The company owns an excellent water power, with four water wheels having an aggregate of 540–hp. The quarry and yard are supplied with five steam derricks, four hand derricks, and three steam drills. The polishing works are well equipped with rubbing beds, column cutters, ball polishers, polishing lathes, etc. Additional equipment consists of one 50–hp. air compressing engine, one 30 arc light dynamo, and four crushers.

The unfortunate condition of the Berlin–Montello Company's affairs, resulting from the business depression, naturally checked the operations and decreased very largely the sale of

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2.

1. MONTELLO GRANITE. 2. BERLIN RHYOLITE.

the stone. As soon as the new company has recovered the natural set-back contingent upon reorganization, there seems to be no reason why the sales will not far exceed those already made.

Statistical Data.

Amount of capital invested: $150,000.00

Facilities at hand for quarrying, 4 waterwheels aggregating 540 horsepower, 5 steam derricks, 4 hand derricks, 2 column cutters, 2 rubbing beds, 8 Jenny Lind polishers, 4 polishing lathes, 1 pendulum, 1 verticle, 4 ball polishers, 4 crushers, 3 steam drills, 1–50 horsepower air compressor, 1–30 arc light dynamo.

Average number of employees: 100.

Wages paid different classes of employees per day:

Stonecutters	$3.00
Quarrymen	1.85
Polishers	1.50
Tool sharpeners	3.00
Laborers	1.25 to 1.50

Cost of cutting and dressing stone per squrre foot:

Pointed	$ .15
Ax-hammered	.60
Bush hammered or chiseled	.85
Polished	1.25

Average value of each grade per cubic foot:

Monumental	$1.00
Building	$ .25 to .50
Paving	.10
Rubble	.04

THE MERKLE GRANITE COMPANY.

The Merkle Granite Co. own several city lots in which is included a small portion of the south end of the large mound. The granite which is quarried at this place is the brighter tinted variety, and is in all respects similar to that which is quarried by the Montello Granite Co. The opening which has been made is small, having been worked but little prior to the formation of the Merkle Granite Co. (See Pl. IV., Fig. 1.) For a number of years the quarry has been worked spasmodically by Mr. O'Brien, a member of the new company, but the main

product was paving blocks. The quarry is now being operated exclusively for monumental purposes. The stripping at this point is not heavy, but will probably increase as the quarry is worked back into the hill. The quarry here, as elsewhere, is traversed by greenstone dikes, from which fine stringers occasionally radiate. The joints, as in the Montello Granite Co.'s quarry, are occasionally cemented or healed with white quartz. The granite from this quarry was not tested, on account of the failure by the company to send the survey the material requested.

The Merkle Granite Co. has built polishing and dressing works at the quarry and are prepared to do all kinds of monumental work. They have been operating only a little over a year, and it is scarcely possible to refer to any important work which they have completed. Nevertheless, the future of this company ought to be very excellent. The granite in which the company is operating has won a national reputation, and it is not required of them to place their product upon the market, as an experiment.

BERLIN AREA.

Berlin is located on the Fox river, in the northeastern part of Green Lake county. (See Pl. VIII.) Situated in the midst of an excellent farming country, the quarrying industry has been merely incidental to the development of the city. The rock which is quarried at this place is often incorrectly spoken of as granite. It is better known as quartz porphyry, but, if given its proper place in the classification of rocks, it should be called a rhyolite. The two mounds from which the rhyolite is quarried are located in Sec. 3, T. 7, R. 13 E., about half a mile from the Fox river. They have an elevation of about 200 feet above the river, and trend for ¾ of a mile in a general NE. and SW. direction. The southwestern slope of the larger mound is within the residence portion of the city, while near the top is located the city cemetery. The two mounds are connected by a somewhat narrow saddle about 30 to 40 feet lower than their

MONTELLO GRANITE.

Sarcophagus of Gen. U. S. Grant.

summits. The exposures at the surface are quite general over the more elevated portions of both mounds. The depth of stripping, or soil covering, varies in different parts of the quarry, but is not sufficiently heavy to prevent economical working.

Quarrying operations have, at different times, been carried on at four or five different places, but at present only two openings, located at the west end of the larger mound, are being worked. The most extensive operations since 1886 have been conducted at the quarry owned by the E. J. Nelson Granite Co., formerly the Berlin–Montello Granite Co., mentioned in the description of the Montello area. The small quarry which is located north of the E. J. Nelson Granite Co.'s works, is owned and operated by Archer McCallum.

THE E. J. NELSON GRANITE CO.

The E. J. Nelson Granite Co. controls about 30 acres surrounding their quarry. Two openings have been made, from each of which a large amount of stone has been quarried. Both openings are somewhat irregular in shape. The first is about 300 ft. long, 200 ft. wide, and 100 ft. deep, and the second is 100 ft. long, 60 ft. wide, and 50 ft. deep. The rock in the quarry is broken into polygonal blocks of various sizes and shapes, by joints, the more prominent of which strike N. 50° W., N. 83° E., N. 82° W., and N. 73°–75° E. The floor of the quarry is uneven, being made up of several planes dipping in various directions and at angles of from 15 to 35 degrees. One can easily infer from the complexity of the jointing that the dimensions which it is possible to obtain must have a very wide range. The largest blocks quarried do not exceed 18 ft. by 4 ft. by 3 ft., while a considerable amount of the stone occurs in such relatively small dimensions that it is unfit for any purposes except macadam and block paving. The fractures in the rhyolite are in some instances completely filled with veins of quartz. The two walls are often so perfectly healed that the rock is more durable at this place than elsewhere.

The rock has differential parting capacities in three directions. The direction along which the rock splits most readily

is known as the "rift." As observed in the quarry the rift has a slight dip to the south and strikes about N. 60° E. at the large opening. At the east end of the mound the direction of the strike changes to N. 73° E. The second and next easiest parting direction is known as the "run." The run is nearly vertical, and strikes at right angles to the rift. The "head" is the plane along which the rock splits least readily, and is nearly horizontal.

The rhyolite from this quarry is a compact, dense rock of uniform texture. The color is, in general, grayish black, but is often given a pinkish tinge by the large feldspars scattered through the groundmass. Occasional small, black streaks occur in the rock, which mar the ordinarily uniform color.

The excellence with which the rock polishes, depends upon the surface which is polished. The "run" and "head" surfaces take a very excellent finish, but the attempts to polish the rift side have never proved satisfactory. From the standpoint of economy in cutting and dressing the stone it is very unfortunate that the rift side will not take a satisfactory polish. In cylindrical columns this difficulty is manifestly not so objectionable as in the square columns. This difference in the perfection of polish, which the stone takes on different surfaces, is due to the structure of the rock. The particles which compose the rock have been elongated and flattened, and it is along the flattened surface that the rock splits most readily and polishes least satisfactorily.

Laboratory Examination.

The Dressed Sample.—On account of the rift and run the rhyolite splits in these directions with an even, regular fracture, and therefore generally has an even, regular rock face, much like the Montello granite. The rock face has a dark, grayish black color, which contrasts nicely with the hammer dressed surface, which is light bluish gray. The polished head of the rock has a dense black background, through which numerous roundish, porphyritic crystals of pink feldspar are scattered. The rift face differs from the head in that the feld-

spar crystals, which are set in the dense black background, have an elongated and flattened outline. The feldspars on the run surface are elongated, but not flattened. The run and rift surfaces are traversed in the direction of the rift by narrow, reddish brown streaks, only noticeable on close inspection. Certain irregularities in the texture of the groundmass, appearing much like included fragments of another rock, are brought out on the polished head. These so-called inclusions often have a slightly darker color than the groundmass, and, in some instances, have a distinctly different texture. So closely do these fragments resemble the groundmass that they cannot be said to be in any way deleterious to the rock. On the other hand, they contribute to the variety of coloring and structure, affording, as previously noted, a pleasing variety to the almost black polished surface. The accompanying plate (Pl. VI., Fig. 2), is an excellent and accurate reproduction of a polished sample of the rock, on the run surface.

Microscopical Examination.[1]—The microscopical examination of the thin section shows the rock to have a finely crystalline groundmass of quartz and feldspar, through which numerous large porphyritic crystals of feldspar and small flecks of biotite are scattered. (See Pl. LXIII., Fig. 1.)

Chemical Analysis.—A chemical analysis of the rhyolite, made by Weidman, in Bulletin No. 3, gives the following composition:

$Si\ O_2$	73.65
$Al_2\ O_3$	11.19
$Fe^2\ O_3$	1.31
$Fe\ O$	3.25
$Ca\ O$	2.78
$Mg\ O$	.51
$K_2\ O$	1.86
$Na_2\ O$	3.74
$H_2\ O$	.44
	99.23

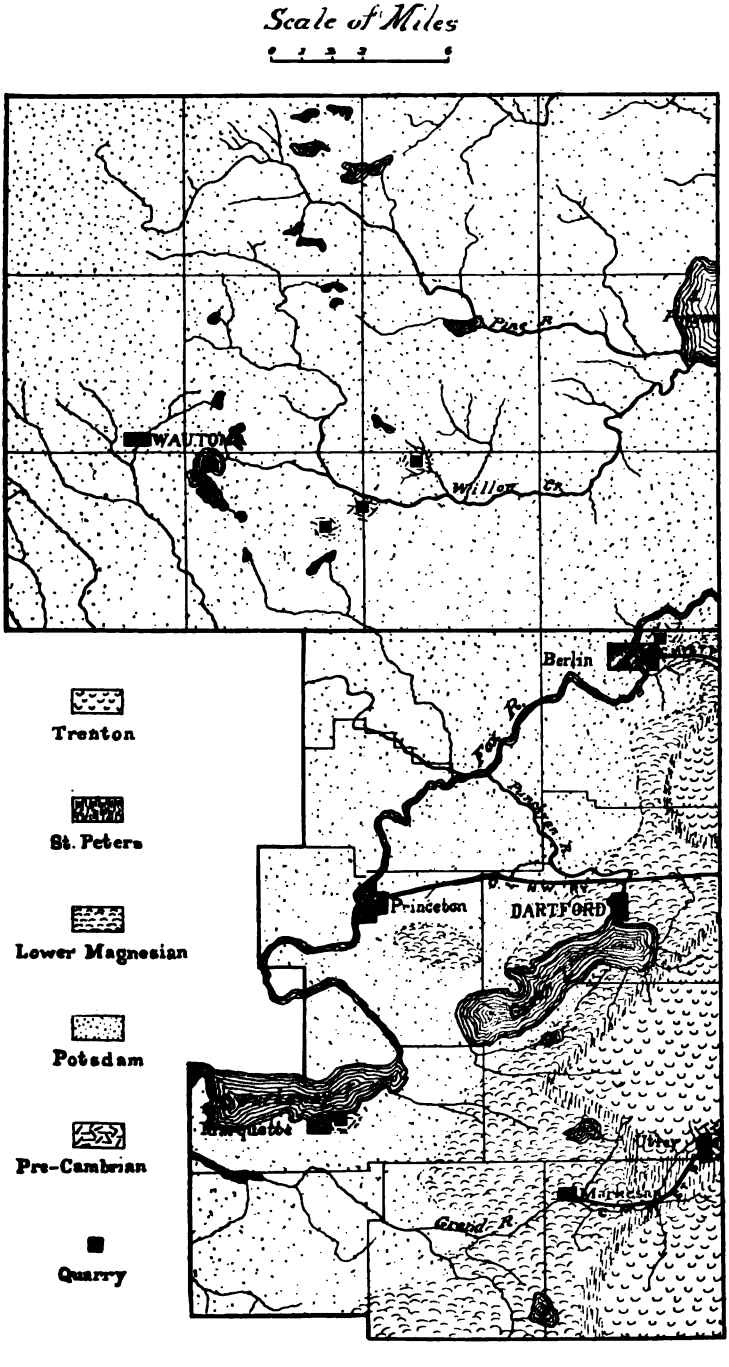
[1] For complete description of this rock the reader is referred to Bulletin No. 3 of the Wisconsin Geological and Natural History Survey, on the Igneous Rocks of the Fox River Valley, by Dr. Samuel Weidman.

The above analysis corresponds in the percentage of silica and aluminum very closely with that of the Montello granite made by Weichmann. (See p. 96.) The percentage of the soda-lime constituents is higher in the Berlin rhyolite, while the percentage of potassium is higher in the Montello granite. The differences between the two rocks are not so much chemical as they are structural, textural, and crystallographic.

Physical Tests.—Reference to Chapter VIII., Table V., of the physical tests, shows that the specific gravity and porosity of the rhyolite correspond very closely with the results obtained for the Montello granite. The specific gravity is 2.641, while the average percentage of pore space, or porosity, is .21%. The result of the temperature tests was also quite similar to that of the Montello. The sample which was exposed to extreme heat was but little injured below a temperature of 1000° F. When heated to 1500° F. and allowed to cool, cracks were formed through the sample in several places.

The loss in weight due to alternate freezing and thawing amounted to about .05 of a gram on a sample weighing over 375 grams, which is equivalent to a loss of about .013 of 1%. The average loss in strength of the cubes, due to freezing and thawing, was 13,075 lbs. per square inch. (See Chapter VIII., Table VII.) This decrease in strength may be, partly at least, attributed to the injury occasioned by freezing and thawing. The average strength of the "frozen" cubes was over 32,500 lbs. per sq. inch, which is considerably above the average tests on ordinary granite.

The maximum crushing strength of the fresh samples, made on two inch cubes, was 47,674 lbs. per sq. inch. This is the highest crushing strength recorded for any rock of which it has been possible to find any record, and places the Berlin rhyolite at the head of the strong rocks of the world. It is interesting to observe that the maximum strength was obtained when the pressure was applied normal to the head. Instead of this one would natur. lly expect the rock to have the greatest strength in either of the other two directions.



BERLIN, WAUSHARA, UTLEY, AND MARQUETTE AREAS.

General Considerations.

The Berlin rhyolite is the strongest, and one of the most durable monumental and building stones on the market. The polished surface of a column will not be perceptibly injured after centuries of exposure. The mineralogical composition, the chemical composition, and the results of the physical tests are all indicative of stability and strength. The only characteristic of the stone, which militates against it, is the occasional occurrence of incipient cracks, black streaks, and veins of white quartz. These should be guarded against and carefully avoided in preparing a block for the market.

The stone has been largely used for monumental purposes, and may be found in many of the cemeteries of the north central states. Fifteen years' exposure to the elements has had no noticeable effect upon the stone, and wherever it has been used, it is as fresh and untarnished today as it was when it left the shop.

The rhyolite is also used for building purposes, and among the important buildings in the construction of which it has been used, may be mentioned Science Hall, Madison, Wis., and the Bartlett Building of Chicago. The rift and run, which are characteristic of the rock, especially adapt it to the manufacture of paving blocks. Hundreds of thousands of these have been cut and laid on the streets of Milwaukee, Chicago, and other large cities, but since the decline in the demand for block paving the number manufactured has been much less. Cross walks and curbing are also cut and sold in considerable quantity. The crushed rhyolite is well adapted for macadam, and has supplied a large demand for this purpose. In short, the Berlin rhyolite is placed upon the market to supply the same demands as the Montello granite. But on account of its somber color and the difficulty with which the rift surface is polished, it has not met with as much favor as a monumental stone, as has the Montello granite. The rhyolite is better adapted for paving purposes, and for macadam it is unsurpassed by any stone on the market. Very beautiful monuments have been constructed by combining the Montello

granite and Berlin rhyolite. The contrast between the cheerful red granite and the almost black rhyolite is very excellent, and for large monuments is worthy of consideration. The two have also, with equally pleasing results, been combined with the lighter colored granite from the Berlin Granite Co.'s quarry.

The E. J. Nelson Granite Co. are prepared to furnish dimension stone for building paving, curbing, cross-walks, and monuments, and crushed rock for macadam. For monumental purposes the stone has heretofore been dressed at the Montello Granite Co.'s works, at Montello; but since the reorganization no arrangements have been made for polishing stone. The quarries at Berlin are equipped with four engines, aggregating 130-hp., three steam derricks, one horse power and one hand derrick, and two crushers. Other information concerning the organization and working of the quarry will be found below.

Statistical Data.

Facilities at hand for quarrying: 4 engines of 130 horse-power, 3 steam derricks, 1 horse power and 1 hand derrick, 2 crushers.

Average number of employees: 100.

Wages paid different classes of employees:

Block makers	**$0.40 per hour.**
Stone cutters	**3.25 per day.**
Tool sharpeners	**3.00 per day.**
Drillers	**2.00 per day.**
Laborers ... From	**1.25 to $1.40 per day.**

Cost of cutting and dressing per square foot:

Pointed	**$0.15**
Ax-hammered	**.60**
Bush-hammered or chiseled	**.85**

Average value of each grade per cu. ft: Building, $0.50; paving, $0.10; rubble, $3.00 per cord; macadam, $1.00 per cu. yd.

THE ARCHER M'CALLUM QUARRY.

The small quarry north of the E. J. Nelson Co.'s works, owned by Archer McCallum, has been operated mainly for paving. The rhyolite at this place is similar in all respects to that at the other quarry. The work is all done by hand, the only equipment being a hand derrick, hammers, crowbars, etc.

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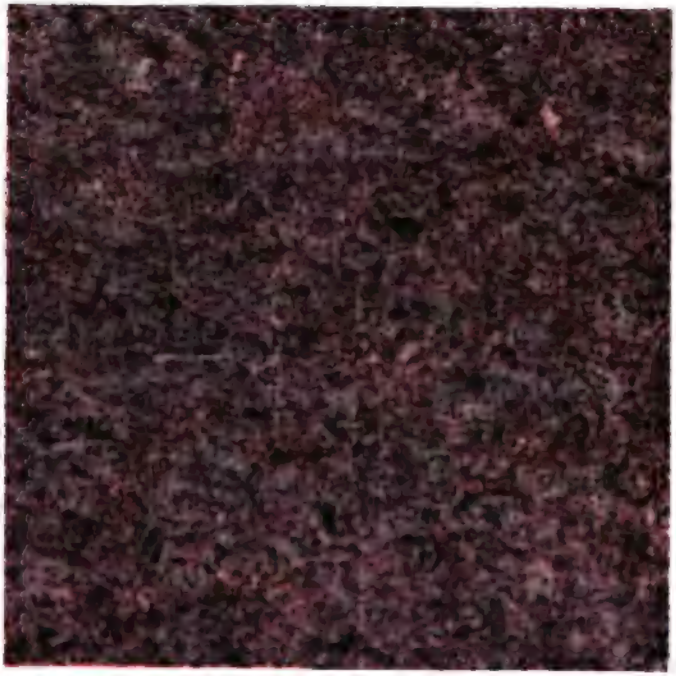

2.

1. WAUSHARA GRANITE. 2. GRANITE CITY GRANITE.

WAUSHARA AREA.

About 12 miles northwest of Berlin, in the town of Warren, Waushara county, several small mounds of granite rise above the general level of the country. On one of these, in the northeast corner of the southeast ¼ of Sec. 18, T. 18, R. 12 E., is located the quarry of the Berlin Granite Co. On another mound, in the southeast ½ of Sec. 8, T. 18, R. 12 E., is located the quarry of the Milwaukee Monument Co. On a third mound, near Spring Lake, in Secs. 22 and 23, T. 18, R. 11 E., a new company, called the Spring Lake and Montello Granite Co., has lately opened a quarry.

THE BERLIN GRANITE CO.

The first quarry in this district was opened by the Berlin Granite Co. in 1889. The members of the present company are Wm. Bannerman, J. Bannerman, D. Horne, and Wm. Horne. The quarries are worked during the entire year, and have been operated each year since they have been opened. Four separate openings have been made. The first one is about 200 ft. long, 100 ft. wide, and 12 ft. deep. The second is about 150 ft. long, 100 ft. wide, and 20 ft. deep. The third is 40 ft. long, 40 ft. wide, and 8 ft. deep. The fourth opening is 40 ft. long, 10 ft. wide, and 8 ft. deep. Some portions of the mound, on which the main openings are located, are covered by a very light mantle of drift, but in many places the rock is entirely devoid of soil covering. The amount of available stone is apparently unlimited.

The weathered surface of the rock is essentially uniform, both in color and texture. The sap of blocks quarried at the surface does not extend to a depth of more than 10 inches on the upper side, and about 1 inch on the under side. The sap decreases, as the depth at which the stone is quarried increases. The color of the weathered surface is white with a tinge of pink. Where the rock has been uncovered in the outcrop for any considerable time lichens have attached themselves to the surface.

The floors of the different openings are comparatively level,

there being in the main opening a dip of only 4° or 5° to the north. The major joints strike N. 30° W. and N. 75°–80° E. An examination of the quarry face and of the natural exposures indicates that dimensions 18 ft. by 3 ft. by 5 ft. can be readily obtained. Stone of almost any desired size, either for monumental or building purposes, can be quarried.

Besides jointing, the granite also has a decided rift which strikes about N. 50° E. This rift facilitates the dressing as well as the quarrying of the stone. The direction of the rift is somewhat obscure and might be easily overlooked by an ordinary observer. The effect which this structure may have upon the strength and durability of the stone will be treated in a subsequent chapter.

Several dikes of coarse granite traverse the quarry in an NW. and SE. direction, but no dark stringers such as occur in the Berlin rhyolite were observed at this locality. The granite appears to be remarkably free from pegmatitic and other veins.

As observed in the different openings, the granite generally has a light pink color, considerably lighter than the Montello granite. This light color changes in certain parts of the quarry to a deeper red, resembling more nearly the Montello granite. The rock is fine grained and has a uniform texture throughout a large part of the quarry. Along the jointing planes the rock is stained with iron oxide, and the sap occasioned by weathering extends to a depth of from two to ten inches below the surface. It would be difficult from an examination of the quarry to designate in just what part the best stock is to be obtained. The stone from the body of the quarry is essentially the same in all parts. Very many of the loose boulders and fragments which have been shoved apart from the main mass of granite, by the action of the glaciers, have been, and are being used for the manufacture of paving blocks and curbing.

THE MILWAUKEE MONUMENT CO.

The quarry of the Milwaukee Monument Co. is located about a mile and a half southwest of the Berlin Granite Co.'s

quarry. The ridge on which the quarry is located is about half a mile long and from 50 to 60 feet high. It is for the most part irregular in outline, but has a general northeast and southwest trend. The granite of which the ridge is largely composed forms an almost continuous outcrop from one end of the hill to the other. The smooth and rounded form of the outcrops at the surface are evidences of glaciation. The stripping is nowhere heavy.

Several sets of joints break the granite into polygonal blocks of various dimensions up to 15 or 20 feet. The major set of vertical joints strike N. 37°–40° W. The next important set strikes N. 52° E. Two other sets with dips in different directions of 10° to 45° constitute the floor of the quarry.

Work has been begun at a number of places along the ridge, but the main opening is near the west end. The granite at this place, to a depth of about 20 feet, occurs in sheets from two to four feet in thickness. The main wall strikes about N. 37° W., and is about 20 feet deep. The opening is quite large, indicating that a considerable amount of stone has been quarried at one time or another.

Several coarse pegmatitic and quartz veins, having a general strike of N. 75-80° W., intercept the granite at this opening. Smaller quartz veins occur in various parts of the granite, throughout the ridge. The sap at this place penetrates the blocks from all sides, often being 11 inches deep on the upper surface. As the quarry is worked deeper it is quite certain that the sap will decrease.

The color and texture of the rock is essentially the same as that quarried by the Berlin Granite Co. The weathered portions are much lighter colored than those which have not been weathered. Some slight differences in color appear on different parts of the ridge.

THE SPRING LAKE AND MONTELLO GRANITE CO.

The Spring Lake and Montello Granite Co. began quarrying in the fall of 1897, on two small mounds of granite about a

mile and a half northeast of Spring Lake postoffice, in Marion township, Waushara county.

The two small mounds are immediately adjacent to each other, and together form what is locally known as the "Island." The mounds are in the midst of an area of low swampy land, difficult of access, except in the winter when the ground is frozen.

The texture of the granite, the jointing, rift, and color, correspond very closely with the granite from the quarries previously described. The depth of sap and the possible dimensions are about the same as given for the granite at the Milwaukee Monument Co.'s quarry.

Laboratory Examination.

The characteristics of the stone from different quarries of this area are so nearly alike that they will be considered together in the following descriptions.

The Dressed Sample.—The examination of a polished and dressed specimen, such as may be seen in the laboratory of the Survey, shows that the granite takes a rock face finish, similar in most respects to that of the Montello granite. The rock face is not bold, but is generally smooth, exhibiting a slightly conchoidal fracture. The color, as previously noted, is lighter than that of the Montello granite. The hammer dressed work also has a lighter color than that of the Montello granite, being a decidedly grayish pink. The granite takes a very excellent polish, the composition of the rock being such that the face has a remarkably clear, smooth finish. The color of the polished surface is a light pink, considerably brighter than the rock face. This pinkish color is due to irregular reddish spots disseminated through the rock. From a short distance, these spots cannot be distinguished from the general grayish pink color of the groundmass, with which they are blended. The contrast between the hammered and polished surfaces is not as striking as might be desired, but it is sufficient to give distinctness to any lettering that may be placed upon the surface. The accompanying plate (Pl. IX., Fig. 1) shows

the color and texture of the rock, of which it is an exact reproduction.

The granite from the Milwaukee Monument Co.'s quarry and from other openings of the Berlin Granite Co.'s quarry, is a shade darker red than that shown in the lithograph of the sample, from the Berlin Granite Co.'s quarry, referred to above.

The finish which the stone is susceptible of taking, both polished and hammer dressed, corresponds almost identically with the stone from the Berlin Granite Co.'s quarry, and is eminently satisfactory.

Microscopical Examination.—Under the microscope, the thin section shows that the Waushara granite is composed essentially of quartz and feldspar. These two minerals constitute at least 90% of the entire rock. Hornblende, muscovite, zircon, and iron oxide are the principal accessory minerals, but constitute such a very subordinate part of the granite that they are of relatively little importance.

Orthoclase and microcline are the main varieties of feldspar, and together they constitute a large part of the sections examined. The orthoclase has been largely altered to microcline, although the cores of certain of the larger individuals are partly muscovite or sericite, and quartz. The individuals of microcline differ widely in size, ranging all the way from the small, almost indeterminable crystals of the groundmass, to the larger, almost porphyritic constituents. The larger individuals show evidence of having been badly mashed or granulated, and one can easily distinguish in the several adjacent fragments of the groundmass the outline of a single original feldspar crystal. Numbers of the larger individuals have been parted along the cleavage planes and the opening thus formed has afterwards been filled with quartz.

The quartz is largely present in small irregular grains. It would be difficult to assert how much of it is a primary or how much a secondary constituent, but it is very probable that the larger part is secondary. The original quartz has been granulated and recrystallized, until it is almost impossible to pass

judgment upon the origin of any particular part of it. But of greater importance than the question of origin, is that of the manner in which the individuals are now aggregated. The large and small individuals, alike, interlock in a very intricate manner, leaving but little pore space and giving evidence of great strength and durability. Plate LXI., Fig. 2, illustrates the structure of the rock, and shows the manner in which the grains unite.

Chemical Analysis.—The chemical composition of the Waushara granite as analyzed by Dr. Samuel Weidman, and published in Bulletin No. 3 of the Wis. Geol. and Nat'l Hist. Survey, is as follows:

$Si\ O_2$	74.62
$Al_2\ O_3$	10.01
$Fe_2\ O_3$	3.85
$Fe\ O$	1.72
$Ca\ O$	2.43
$Mg\ O$	0.33
$K_2\ O$	3.38
$Na_2\ O$	3.33
$H_2\ O$	.24
	99.71

This analysis shows the presence of calcium and sodium, which leads to the presumption that a portion of the feldspar is probably plagioclase. The analysis corresponds quite closely with that of the Berlin rhyolite. (See p. 103.) There is no evidence of the presence of any deleterious constituents.

Physical Tests.—We have learned from the microscopical examination and the chemical analysis that the Waushara granite is composed of very stable mineral compounds, and that they are so combined as to suggest a very strong and durable stone. The physical tests bear out this presumption. Reference to Chapter VIII., Table V., shows that the average specific gravity of the two samples tested was 2.642, which is essentially the same as that of the Montello granite and the Berlin rhyolite. Turning again to the table of physical tests, we notice that there is a similar correspondence in the amount of water absorbed by the samples which averaged .46 of a gram for a mass of about

320 grams. The percentage of pore space or porosity is accordingly .38 of 1% of the total mass of the rock. The samples used to determine the specific gravity and porosity were alternately frozen and thawed each day, for a period of 35 days, and the loss in weight carefully determined. It will be seen by referring to Chapter VIII., Table VI., that the loss in weight of a cube weighing 300.68 grams was nothing. The crushing strength per square inch of the frozen sample from the Berlin Granite Co.'s quarry was over 11,000 lbs. per sq. inch higher than the crushing strength of the fresh one. In the case of the frozen samples from the Milwaukee Monument Co.'s quarry, the crushing strength averaged 2,796 lbs. per sq. in. less. Thus it is seen that the effect of freezing and thawing, as shown by the loss in weight, is so small as to be scarcely a measurable quantity, while the difference in crushing strength is little considering the necessarily small size of the pores.

The samples which were heated in the muffle furnace were little injured at a temperature of 1000° F. Above that, and up to 1200° F., the rock, from all external appearances, was slightly injured, but after being cooled, the sample emitted the peculiar ring, characteristic of granite which has been heated to a red heat. The strength of the rock was very greatly diminished and it may be said that, when subjected to a temperature above 1200° F., the strength of the rock is mainly gone. The high temperature changed the color from pink to light gray, with the faintest possible tinge of pink.

The crushing strength of the rock is given in Chapter VIII., Table II. A sample from the Berlin Granite Co.'s quarry tested 24,800 lbs. per sq. in., while samples from the Milwaukee Monument Co.'s quarry gave a crushing strength of over 38,000 lbs. per sq. in. Other tests (See Chapter VIII., Table VI.), on granite from the Berlin Granite Co.'s quarry gave a maximum crushing strength of over 36,000 lbs. per sq. in., showing that the crushing strength of the stone from the two quarries is about the same. The average crushing strength of all tests on fresh samples was 32,180 lbs. per sq. in. The modulus of rupture was not determined, but it is very evident that the transverse

strength is equal to that of rocks of similar texture and composition.

General Considerations.

In general, it will be observed that the rock quarried by the Berlin Granite Co. and the Milwaukee Monument Co. is equal, in durability and strength, to other granites quarried in this and adjacent states. The results of the tests to determine the injury due to alternate freezing and thawing and extreme heat were very satisfactory, and the strength of the stone is much higher than is ordinarily required for the purposes for which the quarry is prepared to furnish stone.

Stone from these quarries has been used mainly for monumental work and paving, although coursing, pier, cross-walk, and curbing stone have all been manufactured in large quantities. For monumental purposes, the modest subdued color has made this stone less attractive than the more brilliant granites, and it is for this reason, and no other, that it has not met with a very large demand in the monumental market. Either alone or in combination with other brighter stones, the Waushara granite may be used to excellent advantage. As the quarries are worked to a greater depth, the granite has a brighter tint, approaching nearer the color of the Montello granite, than any other in the state.

As a building stone it is well adapted for all purposes of construction. Dimensions of any reasonable size may be obtained, and the capacity which the stone has to withstand frost and heat gives it an added value for this work. Probably no granite quarry in the state is better suited for the manufacture of paving blocks, cross walks, and curbing than that of the Berlin Granite Co. The fine, generally uniform texture of the rock, the uniformly smooth head, and the facility with which it can be split, make it one of the most admirable stones for these purposes. The stone has been furnished to the Milwaukee Street Car Co. and used on Broadway and Wisconsin streets to protect the asphalt from wearing next to the rails. The C., M. & St. P. Ry. Co. used the stone at the tracks of

their depot in Milwaukee in 1894. In both cases the stone has proved perfectely satisfactory.

It will be seen by referring to the data which follow on p. 116, that the Berlin Granite Co. has been doing an increasing business since 1892, something which is remarkable, considering the general condition of the quarrying industry in the state. The business of the company is not large, but when one considers that the quarry is located 12 miles from the nearest railway station, and that the stone has to be hauled by team the entire distance, he can appreciate that the stone is not only of excellent quality but also easily quarried and worked.

The quarry of the Milwaukee Monument Co. has not been operated since 1896. The Spring Lake and Montello granite Co. have only been operating about a year.

Considering together the quarries of the Milwaukee Monument Co., the Spring Lake and Montello Granite Co., and the Berlin Granite Co., Waushara county may be considered one of the best prospective centers for quarrying yet opened in the state. It is thought that, before many years, railroad capital will be convinced of the desirability of extending transportation facilities into this region, which will very greatly assist in its future development.

Statistical Data of the Berlin Granite Co.

Amount of capital invested: $5,000.00.

Facilities at hand for quarrying: 2 hp. derricks.

Average number of employees: 18.

Wages paid different classes of employees: Blaster, $2.50; blacksmith, $2.25; drillers, $2.00; paving cutters paid by the piece.

Cost of cutting and dressing per square foot:

Pointed	$0.25
Ax-hammered	.50
Bush hammered or chiseled	.80
Polished	1.50

Cost of transportation: By rail to Chicago, $1.20 per ton.

Average value of each grade per cubic foot: Paving blocks, $0.30; monuments, $1.00; building stone from $0.50 to $1.50.

Shipments for the past five years:

1892, paving blks., 500 tons; monument stone, 20 t.
1893, paving blks., 1000 tons; building, 100 t.
1894, paving blks., 1500 tons; monument stone, 30 t; Building, 300 t.
1895, paving blks., 2000 tons; building, 200 t.
1896, paving blks., 4525 tons; cross walks 100 t. Mon. & Bldg., 100 t.

Statistical Data of the Milwaukee Monument Co.

Average value of each grade per cubic foot: Monumental, $1.50.
Shipments for three years:

1893	3,000 cubic feet.
1894	100,000 paving blocks.
1896	200,000 paving blocks.

UTLEY AREA.

THE GREEN LAKE GRANITE CO.

One of the important rhyolite knobs of Green Lake county is located in the center of Sec. 36, T. 15, R. 13 E., on the C., M. & St. P. Ry., near Utley. (See Plate VIII.) Quarrying operations were begun at this place in 1884 by the Green Lake Granite Company and have continued up to the present time. The quarry is situated on the north side of the somewhat steep mound which rises to an elevation of about 100 feet above the railroad at its base. The exposed portions of the rhyolite are very large, and quarrying operations have been carried from the west end nearly half way around the hill to the north. The quarrying operations have extended into the hill in a very irregular manner leaving a rough, jagged face. The rock is broken into irregular blocks by three relatively prominent jointing planes, which strike respectively N. 65° E., N. 43° W., and N. 60–75° W. These joints are so close that it is difficult to obtain any but small dimension stock. Other joints occur which are often of an incipient nature and as such they do not appear until the stone is being worked. The rhyolite also exhibits a decided rift, along which direction, parallel to the surface, it parts more readily than in other direc-

BERLIN RHYOLITE.

Monument in the National Park, Gettysburg, Pa.

tions. On the north side of the hill the rift has a slight dip to the north, while on the south side the dip is apparently south.

The rock, as observed in the quarry, has much the appearance of the rhyolite from Berlin, but has in general a blacker color, and contains, besides porphyritic pink feldspar small roundish, glistening crystals of quartz. The exposed surface of the rock weathers evenly. The shallow depth to which disintegration has gone and the growth of lichens both give evidence of the durability of the stone.

Laboratory Examination.

The Dressed Sample.—The specimen in the laboratory of the Survey shows that the rock will take a very high polish. Through the intensely black groundmass there are disseminated numerous roundish pink feldspar crystals, and clear, translucent quartz grains, which give a very pleasing effect to the color of the polished surface. The parts that are hammer dressed have a somewhat lighter color than the polished face, making a favorable contrast. Except along the rift where the fracture is comparatively smooth and even the rock breaks with a splintery, rough, and often conchoidal fracture.

Microscopical Examination.—The mineralogical composition and texture are best understood after an examination of the thin section under the microscope. Such an examination shows the rock to consist of a fine cryptocrystalline groundmass, through which is disseminated numerous large and small porphyritic crystals of feldspar and quartz, and occasional sections of hornblende, biotite, and other subordinate minerals. The groundmass is composed of finely crystalline quartz and feldspar in individuals so minute that it is scarcely possible to differentiate one mineral from the other. The large feldspar crystals are more abundant than the quartz, and have peculiarly irregular outlines. Certain of the feldspars are simple individuals, others are twinned, while there is still a third class which are intergrowths of two varieties. The feldspar is generally fresh, but occasionally small areas may be observed that are partly altered to quartz, sericite, and other

minerals. The quartz individuals have, as a rule, a regular outline, and appear decidedly clear in the dense groundmass in which they are imbedded. Magnetite and sometime pyrite are disseminated in small grains through the rock. The thin section shows numerous veins of quartz and feldspar, which were originally fracture planes, now well cemented. In general, the size and arrangement of the individual grains point to a strong and durable rock, equal in all respects to those previously described. The general structure of the rock and arrangement of the individuals are nicely shown in the accompanying plate. (Plate LXIII., Fig. 2.)

Chemical Analysis.—The chemical composition of the rhyolite, as determined by Dr. Samuel Weidman,[1] is as follows:

SiO_2	73.09
Al_2O_3	13.43
Fe_2O_3	2.57
FeO	2.57
CaO	2.29
MgO	1.03
K_2O	1.58
Na_2O	3.85
MnO	Trace
H_2O	.72
	101.13

The sample analyzed contained small percentages of CO_2, sulphur, and zirconium, none of which were quantitatively determined in the analysis. This analysis shows a high percentage of silica and a relatively low percentage of iron, both of which indicate a durable stone.

Physical Tests.—The specific gravity of the Utley rhyolite was determined to be 2.645, and the porosity .019 of 1%, which is the lowest pore space of any stone tested. The strength of the stone was not determined, but it is very certain from the microscopical examination and the porosity test that it is very high.

[1]Bul. No. 3, Wis. Geol. and Nat. Hist. Survey.

General Considerations.

It may be said in general that the color of the stone is relatively permanent, and the durability and strength are all that can be desired, either for monumental, building, or road construction. On account of the difficulty experienced in obtaining large dimensions and the uncertainty attending the successful working of the blocks, due to incipient joints, the stone has not been very largely used for either monumental or building purposes. Its main use has been in road construction, either as block paving or macadam. For these purposes the stone seems to be very well adapted. Blocks for paving are not as readily cut as at Berlin, on account of the less pronounced rift, but this is mainly an item in the economy of working the quarry, and does not affect the durability. The Utley rhyolite is well adapted for the manufacture of macadam, and it is manly for this purpose that the stone is exploited. The numerous joints are an advantage in exploiting the stone for macadam, and the close texture and fine grain of the rock give it a capacity to resist abrasion, scarcely equalled by granite.

The Green Lake Granite Co. are prepared to furnish stone for monumental, building, macadam, and paving purposes. The market for their product has heretofore been mainly Chicago, but with the increased demand for macadam throughout Wisconsin, it should be in use in the construction of roads in many of the cities of this state.

Statistical Data.

Amount of capital invested: $120,000.00.

Facilities at hand for quarrying: 1-120 horse power engine, 4 crushers and pulverizers.

Average number of employees: 30 to 50.

MARQUETTE AREA.

NOBLE'S QUARRY.

On a knob of rhyolite located in Secs. 34 and 35, T. 15, R. 11 E., near the south shore of Puckaway lake, is a quarry known as Noble's quarry. (See Plate VIII.) The height of the

knoll above the river is about 125 feet. The area of the hill was not determined, but comprises at least several acres and the amount of available stone is therefore practically unlimited. Quarrying has been pushed back into the hill for a distance of about 50 or 60 feet, and the opening now has three faces with a maximum depth of 50 feet. The quarry has not been operated for a number of years, owing to the lack of transportation facilities. When operated, it is necessary either to haul the stone by team a distance of 14 miles to the nearest railway station, or transport it down the Fox river on scows built for the purpose.

The natural exposures of rhyolite have a dull gray color, and show but little disintegration from weathering. Wherever the rock is not covered with moss or soil, lichens grow abundantly on the surface. The stone is broken into polygonal blocks by numerous jointing planes, which strike N. 87° E., and about north and south. These jointing planes are very prominent, and constitute the walls of the large quarry opening. The floor of the quarry is formed by a number of jointing planes dipping at different angles and in different directions. One of these jointing planes dips at an angle of 15 degrees to the north, and another dips at about the same angle in the opposite direction. It is possible by careful selection to quarry blocks 5 ft., by 5 ft., by 6 or 8 ft. Blocks of this size are not abundant in the quarry, the major portion of the rock being broken into much smaller dimensions. A careful examination of the surface of the natural exposures, south of the quarry opening, shows that along what may be called fracture zones, the rock is broken into very small blocks. Between these zones the joints are farther apart, and consequently the blocks obtained are of larger and better dimensions. Nevertheless it is to be noted, that one of the difficulties in working this quarry for monumental and constructional purposes, is to obtain with ease stock of large dimensions. It might be necessary to work over a large part of the quarry before a block of the required size could be obtained. When it comes to exploiting the stone for the manufacture of macadam, the close fracturing is, of course, advantageous.

The rock has a rift which is almost vertical, and strikes about east and west. It is most distinctly marked by the streaky appearance of the rock in the natural exposures adjacent to the quarry opening.

The general color of the rock is black, speckled with porphyritic crytsals of pink feldspar and translucent blebs of quartz. The color corresponds very closely to that of the Utley rhyolite previously described.

The rhyolite polishes very beautifully, and where the rock can be obtained in sufficiently large dimensions, free from incipient cracks, it is very suitable for monumental purposes. The stone has never been used to any extent for either monumental or building purposes, because of the difficulty which is encountered in obtainning sufficiently large dimensions, but it has been quarried mainly for road construction, in the shape of paving blocks and crushed stone. For these purposes it is well adapted, although it is thought that the difficulty in cutting the paving blocks, might make them too expensive for profitable manufacturing.

There is a considerable question as to whether it will be profitable to work this quarry, until railway facilities are brought much neaier than at present. It is very difficult for a quarry, which is located some distance from a railroad, to successfully compete with those having transportation facilities immediately at hand. But, nevertheless, in spite of the difficulties of transportation, during the time when the demand for paving blocks was very large, the stone was successfully quarried and carried by water from Puckaway lake, by way of the Fox river, to the nearest markets. For this purpose, a dock, which no longer exists, was built on the lake shore at a point near the quarry. Such a method of transportation appears, at this time, to be impracticable, and the quarry must await new developments.

GRANITE CITY AREA.

The tongue of igneous rocks extending south from the main crystalline area of north central Wisconsin, through Waupaca

county, is largely composed of granite, more or less covered with drift. (See Plate XIV.) From Granite City in the town of Wyoming, Waupaca county, north as far as Hunting, granite outcrops at many places.

HUNTING.

At Hunting, which is the junction of the Omaha with the Big Falls railroad, an abundance of undeveloped granite outcrops a short distance from the tracks. An exposure, covering several acres and having a south face of ten to fifteen feet, presents a very accessible place for quarrying. The main joints at this locality strike N. 40° E., and N. 40° W. Other sets were observed which had strikes of N. 35° W. and N. 65° E., respectively. These principal jointing planes are 2, 4, 6, and 8 feet apart. The joints striking N. 65° E. are in certain places as much as 25 feet apart. From these observations it is quite evident that very excellent dimensions can be readily obtained at this place.

The weathered surface of the granite is grayish white. Disintegration has not penetrated to a greater depth than two inches, and the fresh surface shows a medium grained pink colored groundmass, in which are embedded occasional large porphyritic crystals of feldspar. These porphyritic individuals are often as much as an inch long, by a half or two-thirds of an inch thick. With the exception of the abundant porphyritic sonstituents, the granite is very similar to that which has been quarried at Granite City. There is little question but that the granite at this place will before many years be utilized for some purpose.

GRANITE CITY—LEUTHOLD QUARRY.

At Granite City, in the west central part of the town of Wyoming, is located a quarry, known as the Leuthold Quarry. For a number of years the granite from this quarry had an extensive sale in the north central states, both for monumental and paving purposes, but, owing to financial and other difficulties, the quarry has been idle for several years. The granite is

QUARRY AT GRANITE CITY.

Leuthold's Quarry.—New Opening.

naturally exposed in oval elongated mounds or ridges, sparsely covered with soil, known by geologists as "rôches moutonnées." The longer axes of these mounds have a general east and west direction, and the V-shaped trenches, 8 or 10 feet deep, between the smaller ridges, have much the appearance of glacial gougings.

Here, as elsewhere, there are two prominent sets of joints striking respectively N. 80° E. and N. 10° to 15° E. These with other joints break the rock into polygonal blocks, the largest observed measuring about 6 ft. by 8 ft. by 10 ft. The surface of certain knobs adjacent to the one on which the quarry is situated, have a surface which is very much fractured by numerous short, close joints, one to six feet long, two to ten inches apart, and striking N. 80° E. It is possible that these joints do not extend to any considerable depth below the surface, and their presence may be due partly to a combination of weathering and forest fires. In areas where forest fires have been prevalent, it seems very probable that the stone at the surface may be materially injured by the heat from the burning of the debris strewn over the surface. This heat may even be so intense as to develop joints at the surface, in the direction of easiest parting.

The color of the granite after it has been exposed to the weather for a very long time is essentially gray. Small pits, resulting from the occasional weathering of a large porphyritic crystal of feldspar, may be observed on the exposed surface. These pits are often from a fourth to a half inch long and an eighth of an inch deep, while, exceptionally, larger ones are found an inch in length. Otherwise, the weathered surface is uniform throughout. The sap does not extend to a depth of more than two inches.

The fresh surface of the granite has two quite distinct shades of color. The brighter colored variety has a reddish tone, while the other is a gray with the faintest tinge of red. The difference in color is due to the feldspar, which in the red variety has a much deeper red color than in the gray. The brilliant small red feldspar individuals give the rock a very attrac-

tive appearance. The granite immediately at the quarry is remarkably free from the porphyritic feldspar. An occasional inclusion of a foreign rock occurs in the quarry, which detracts from the value of the stock for monumental work.

The granite is cut in a number of places by coarse pegmatitic veins, often a foot and a half wide. None of these large veins intercept the granite immediately at the quarry, although a number of smaller ones were observed.

The company that operated the quarry worked three different openings. One of the two openings at the east end of the mound has a face of 25 feet. The other is about 125 feet long by 75 feet wide by 40 feet deep. The floor of each of these openings is uneven, and the main wall has been worked across the natural face. The third opening has a natural face of about 15 feet, and the indications for obtaining good stock are better than at either of the other openings. (See Pl. XI.)

Laboratory Examination.

The Dressed Sample.—The polished surface of the granite has a very pretty red or gray color. The finish is not brilliant, but rather mild. The color and texture are nicely shown in the accompanying plate. (Plate IX., Fig. 2.)

Microscopical Examination.—The examination of the thin section under the microscope shows a rock having a holocrystalline, granitic texture. The individual grains are close fitting, and interlock in a very intricate manner. The main constituents of the rock are feldspar, quartz, and biotite. Feldspar is the most abundant and consists mainly of orthoclase and microcline. Many of the feldspar individuals have a dirty, cloudy appearance, due to minute particles of iron oxide, which are the source of the red color of the rock when viewed macroscopically. Small flakes of secondary muscovite or sericite are disseminated quite abundantly through the feldspar individuals. Quartz, which is the next constituent to feldspar in point of abundance, is easily distinguished from the feldspar by its clear and lucid character. It constitutes a very important part of the granite, contributing both strength and durability.

The third important constituent is biotite, which occurs in medium sized grains quite uniformly disseminated through the rock.

Physical Tests.—As a result of the physical tests the average specific gravity was found to be 2.676, and the pore space .372 per cent. (See Chapter VIII., Table V.) Freezing and thawing for 35 days, as shown in Table VI., did not decrease the weight of the sample. The average crushing strength of the frozen specimen was 14,886 lbs. per sq. in., or 10,000 lbs. per sq. in. less than the crushing strength of the fresh sample. The crushing strength of the fresh sample was 25,000 lbs. per sq. in. The loss of 10,000 lbs. was at least partly due to the somewhat irregular shape of the sample tested.

General Considerations.

The results of the above examination indicate that, as far as durability and strength are concerned, the granite from this quarry is eminently suited for most classes of monumental and constructional work. The quarry is well equipped with tracks, polishing works, and other necessary equipment, but is now idle, awaiting the cessation of litigation and the appearance of new capital. The amount of good granite in this vicinity is unlimited, and the close proximity to the railroad makes the quarry especially desirable. The granite takes a very good polish, works with comparative ease, and is well suited for certain classes of monumental work. It is perhaps not as durable as the granites containing a less percentage of mica and more quartz, and yet it is well suited for a large class of monumental work. It can be used to advantage for building purposes, macadam, and block paving. Difficulty might be experienced in securing a very great quantity of large dimension stock for heavy constructional work, but for lighter masonry no such difficulty would be met. The composition of the granite shows that it is well adapted to the manufacture of macadam. Its wearing quality is probably not as great as that of more siliceous rocks, but the greater facility with which it can be crushed ought to place it upon the market at a lower price.

In time there will be a large demand for this granite, and even today monument workers, who have once used the stone, are making inquiries with reference to it. The moderate ease with which it is cut and dressed allows it to be placed on the market at a price that meets the demands of those who cannot pay for a more expensive granite, such as the Montello.

WAUPACA AREA.

WAUPACA GRANITE CO.

The Waupaca Granite Co.'s quarry is located south of the Granite City area, on a tongue of igneous rocks, which extends from the main crystalline area in Shawano county, through the eastern portion of Waupaca county, to within 6 miles of the Waushara county line. (See Plate XIV.) The quarry is situated about 5 miles north of the city of Waupaca, in the midst of a rough glacial country. The hill on which the quarry is located rises about 100 feet above the general level of the country, and is composed almost entirely of granite, there being only a light stripping of boulder clay and soil. An examination of the hill shows that it is composed of at least three different kinds of granite, which may be readily distinguished from one another by marked differences in texture and composition.

Only one of the three kinds of granite is quarried. The opening, from which this is taken, is situated at the south end of the hill. The quarry was opened in 1886, and since that time has been operated four years, including 1896 and 1897.

The single opening which has been made is about 90 feet deep and extends along the face of the cliff for a distance of about 100 feet. Besides the granite which has been taken out of the hill at this place, a number of boulders of large dimensions, on the east side of the hill, have been worked into saleable stock. The company controls 40 acres of land surrounding the quarry, and the amount of granite which is easily accessible is practically unlimited.

An examination of the quarry face and the natural exposures

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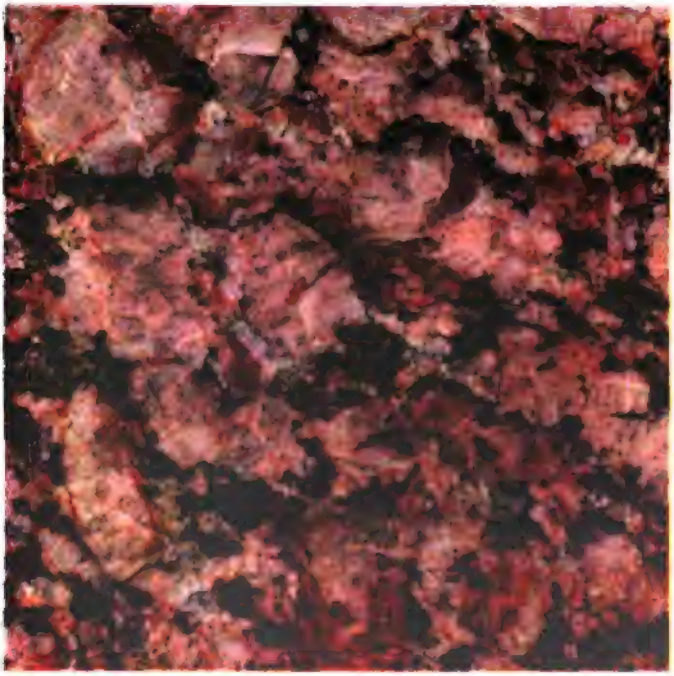
2.



1. RED WAUPACA GRANITE. 2. GRAY WAUPACA GRANITE.

reveals several sets of joints, which traverse the quarry in as many different directions. The main set, which forms the back wall to the quarry, strikes about N. 75° E., with a dip from the vertical of about 5 degrees to the south. The second set strikes about N. 12° E., and the third strikes N. 83° E. Besides these major joints, the rock is traversed, in various other directions, by parting planes having no regularity of occurrence. The major joints are usually continuous, extending beyond the limits of the quarry, but the others are discontinuous, being confined to the quarry or even to a portion of the quarry. In places the fractures are close, and traverse the quarry in zones, breaking the rock into fragments varying from a few inches to several feet in thickness. Between these zones of close fracturing, the joints are much more open, and dimension stock may be obtained often 10 or 12 feet by 6 feet by 4 feet. The finer seams are occasionally filled and perfectly sealed with chlorite. In other instances, seams which cannot be detected in the stock, as it is taken from the quarry, appear after the dressing has neared completion. The natural exposures on the west slope of the hill, are the least fractured of those anywhere observed, and it is thought that an opening at this place would furnish stock of the largest dimensions.

The weathering of the granite in the natural exposures is very uneven. The weathered surface is rough and pitted, showing that the rock is composed of mineral constituents of different degrees of hardness, the softer of which weather out the more rapidly. The exposed surface of the granite is here, as in other quarries, covered with an abundance of lichens. These growths merely indicate that the rock, as a whole, weathers slowly.

The color of the granite from this quarry differs quite widely. The commonest color is a combination of black and pink, called gray. (Plate XII., Fig. 1.) The other color is a combination of green and pink, known as red. (Plate XII., Fig. 2.) The pink feldspars predominate very largely in all the varieties, while the green and black minerals mingle in various proportions to give all gradations between the so-called gray and red varieties.

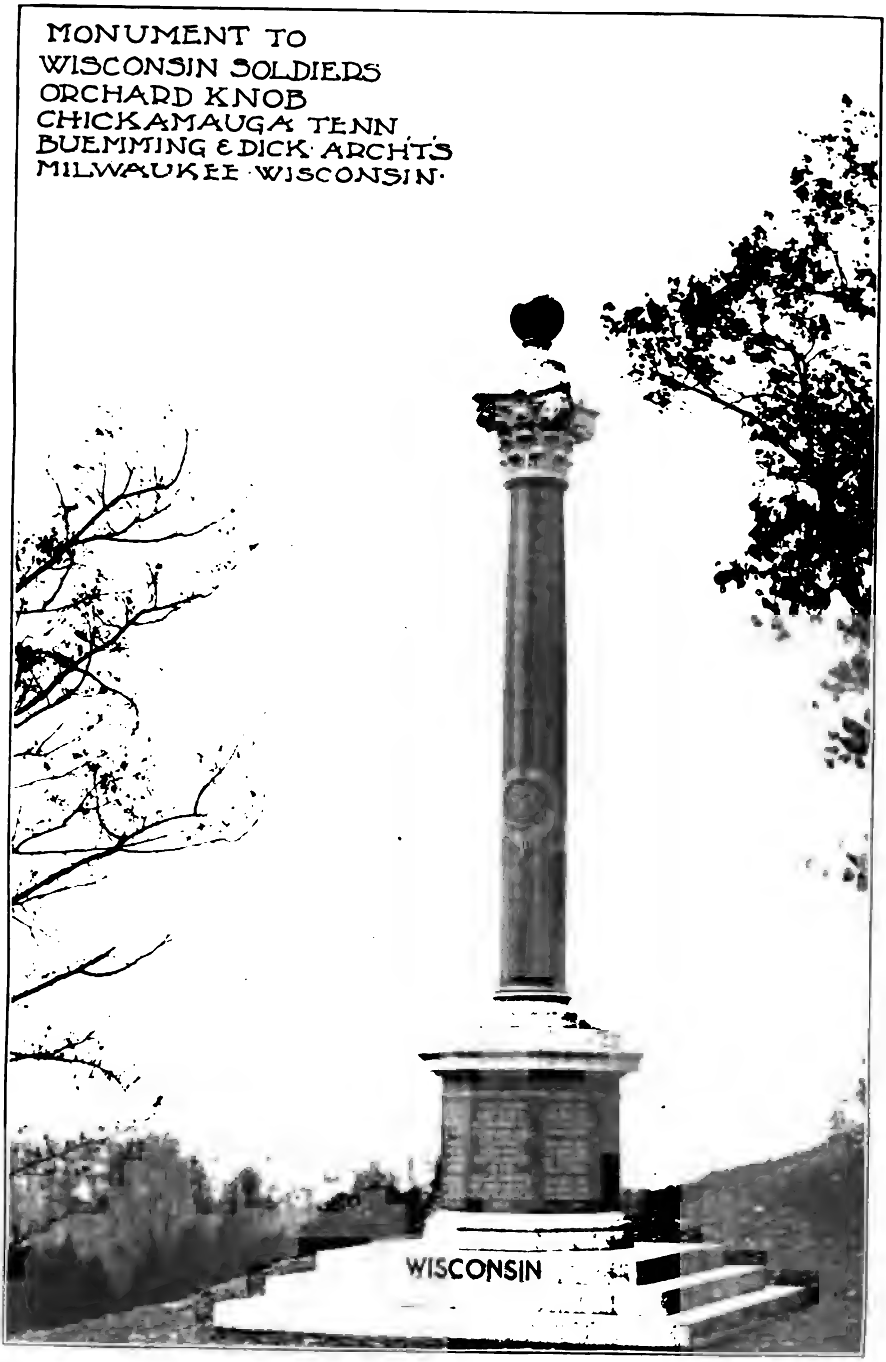
The rock consists mainly of large individuals of feldspar, between which are disseminated small crystals of feldspar, quartz, hornblende, biotite, chlorite, and epidote. The flesh colored feldspar contributes the reddish tinge to the rock, while the biotite and hornblende are the sources of the black. The green color of the red variety is due to the abundance of epidote and chlorite occurring with the porphyritic crystals of feldspar. Occasionally the rock is stained along the jointing planes with iron oxide. Green streaks of chlorite or epidote sometimes traverse the rock, as above mentioned.

Laboratory Examination.

The Dressed Sample.—An examination of samples, similar to those in the laboratory of the Survey, shows that the granite takes a very desirable polish. The variety which contains a large percentage of hornblende and biotite, is less susceptible to a brilliant polish than the one which is nearly free from such ingredients. But considering the coarseness of the constituent minerals, it may be said that the polished surface is very excelcellent. The red variety takes a polish which is more lasting than the gray, which may be attributed to the fact that epidote in the first variety takes the place of biotite in the latter.

The large porphyritic feldspar crystals, of which the granite is mainly composed, average from ¾ to 1 inch in diameter, although occasional individuals measure as much as an inch and a half. The hammer dressed surface of the granite has a pinkish red color, differing but little from the color of the polished surface. The contrast between the hammer dressed and polished surfaces is not very sharp. The rock face is rough and irregular, standing out in bold contrast to the hammer dressed and polished faces. Stone cutters experience some difficulty in dressing sharp corners on the stone, on account of the readiness with which the feldspar breaks along its cleavage planes. This unfortunate characteristic often entails additional expense in cutting and dressing the stone.

One of the pleasing features of columns built out of this granite is that no two faces have exactly the same details of tex-



WAUPACA GRANITE.

Monument in the National Park, Chickamauga, Tenn.

ture or color. If one examines in detail the four sides of a monument built out of Waupaca granite, he will find that each has a distinctly different mottling and color. The large size of the porphyritic feldspars, and their uneven arrangement, combined with the constantly varying proportions of biotite and epidote, give detailed effects which are never the same on two different surfaces. The color and texture of the two extreme varieties are accurately reproduced in Plate XII.

Microscopical Examination.—The porphyritic texture of the granite can be best observed in the hand specimen, but the mineralogical composition can be best determined with the aid of a microscope. Such an examination shows that the other important constituents, besides feldspar, are quartz, epidote, ziosite, biotite, hornblende, and chlorite. Among these, epidote appears to predominate in certain sections, while either quartz or biotite is the most abundant in others. The only remaining constituent of importance is iron oxide, which gives a reddish color to the porphyritic feldspars and portions of the matrix.

The feldspar consists of several varieties, including orthoclase, microcline, and plagioclase. Intergrowths of two of these, forming microperthite, are not uncommon. The feldspar individuals are all more or less decomposed, the principal alteration products being zoisite and epidote. The lesser alteration products are quartz, chlorite, and sericite or muscovite. Biotite and hornblende are unaltered in the fresher sections, but where the granite has been much decomposed, chlorite has developed as a product of either one or both of these minerals. Where biotite and hornblende predominate, decomposition has not proceeded as far as where chlorite and epidote are more abundant. The green variety is only a phase of the black, in which decomposition has very largely altered the biotite, hornblende, and feldspar to chlorite, epidcte, and other products.

The larger individuals have been both granulated and recrystallized. The quartz grains, as a rule, show more or less undulatory extinction, and many of the feldspars are cracked or bent. The individuals interlock in an intricate manner, as shown in Plate LX., Fig. 1. The granulation and decompo-

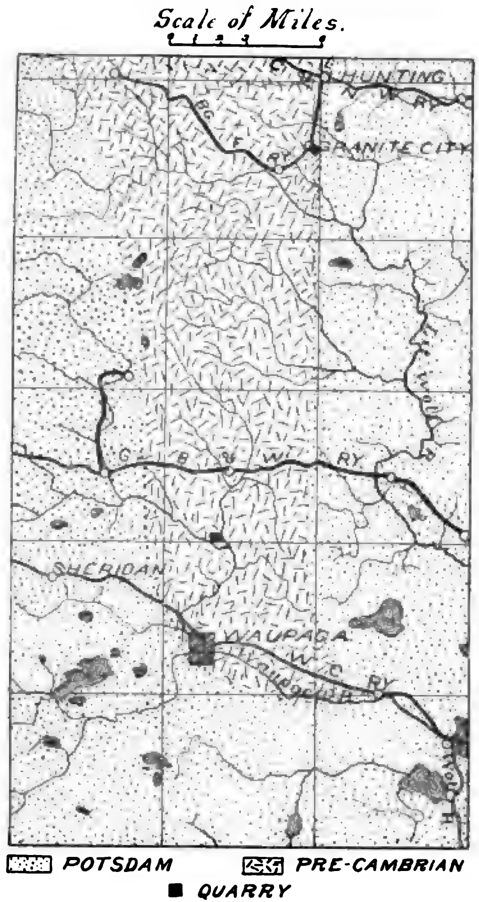
sition of the feldspar may have lessened somewhat the strength of the rock, but not enough to decrease its usefulness.

General Considerations.

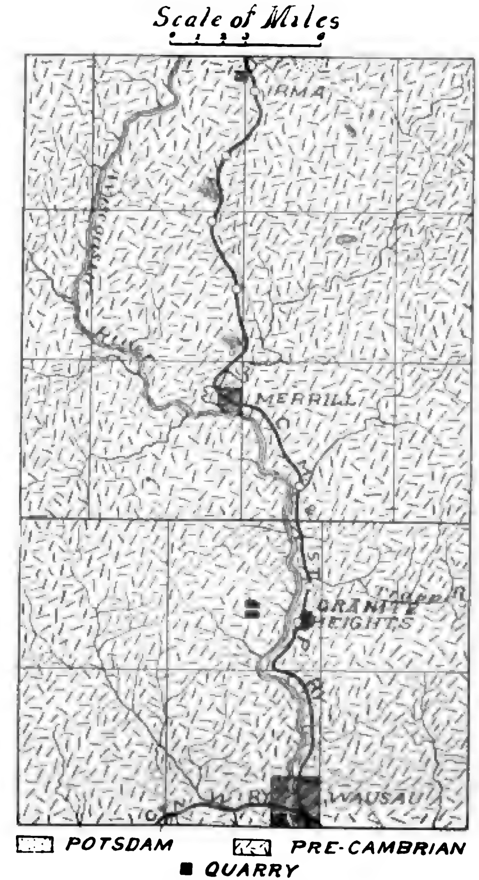
The macroscopic and microscopic examinations of the rock, combined with its physical characteristics, indicate that the Waupaca granite is best suited for inside ornamental work, although monuments and mausoleums constructed therefrom may stand uninjured for many decades. The green tinted or red variety is thought to be better adapted to withstand climatic changes than the gray.

The Waupaca granite has been used very largely in Chicago and elsewhere, both for constructional and ornamental work. Among the more important buildings, in the construction of which it has been used, may be mentioned the Omaha Bee building and the gateway to Lake View cemetery, Minneapolis; the chapel and gateway to Graceland cemetery, the Telephone building, and the Gus Wilkie residence, Chicago. The Wisconsin State Soldiers' monument at Chickamauga, (See Pl. XIII.), and the columns in the Wm. Balcome monument in Forest Hill cemetery, Chicago, are among the more important monumental works built out of Waupaca granite.

The durabilty of polished columns of the red variety is shown by a large column which has stood for ten years in the yard of the company, and is as perfect today as it was when first finished. On account of the ready cleavage of the feldspars and the coarseness of the biotite, it is thought that the granite from this quarry can be worked with much greater facility and to better advantage into cylindrical columns than into square cornered work. There is probably no more beautiful or brilliant stone quarried anywhere in the country for inside ornamental work, wainscoting, columns, or balustrades, than that which is taken from the Waupaca Granite Company's quarry. Difficulty has been experienced here, as elsewhere, in securing, without special effort, very large dimensions; but for ordinary dimensional purpose, monumental work, or wainscoting, an abundance of material easily accessible can be found in most parts of the quarry.



WAUPACA AND GRANITE CITY AREAS.



GRANITE HEIGHTS AREA.

The works of the company are equipped with water power, and polishing and cutting works adjacent to the quarry. The economical working of the quarry has been hampered by the lack of transportation facilities, it being necessary to haul the stone by team, a distance of 5 miles, to the nearest railroad station. But in spite of this difficulty, the granite has attained an enviable reputation in the market, in competition with other more easily accessible granites. It is thought that before many years this granite will be one of the leading ornamental stones in the country.

Statistical Data.

Amount of capital invested: $40,000.00.

Shipment for 1896, 2000 cu. ft.

Facilities at hand for quarrying: 1 steam derrick, 30 hp. engine, 1 gang saw, 1 hand derrick, 2 polishing surfacers, 1 polishing lathe, 1 column cutting lathe.

Average number of employees: 12.

Wages paid different classes of employees:

Stone cutters	$3.25
Drillers	1.50
Laborers	1.25

Cost of cutting and dressing per square foot:

Sawn	$ .30
Pointed	.20
Ax-hammered	.30
Bush-hammered or chiseled	.75
Polished	1.00

GRANITE HEIGHTS AREA.

One of the first granites quarried in Wisconsin occurs at Granite Heights, about ten miles north of Wausau. This granite, although not found immediately at Wausau, is widely known as the "Wausau Granite." It is very abundant and outcrops at numerous places over an area of many square miles. It extends continuously in a broad belt on either side of the Wisconsin river from Granite Heights north as far as Pine river, a distance of about 5 or 6 miles. The granite outcrops

at many places along the bluffs adjacent to the river, over this entire distance. In the direction of Wausau, outcrops occur on the east side of the river, for about a mile south of the Heights station, where the C., M. & St. P. railroad skirts the foot of a somewhat steep bluff. The bluff has an elevation of about 200 feet above the river, and extends parallel to it for a distance of about a mile. Along this entire distance the granite outcrops almost continuously. These outcrops are mainly in Secs. 23, 24, and 26, T. 30, R. 7 E., and on them are located the L. S. Cohn Granite Quarries.

West of the Wisconsin river, at this place, the escarpment is distant about a mile and a quarter. Here, as on the east side of the river, excellent exposures of the same granite are found. The bluffs rise to about the same elevation, but with a much gentler slope. The vertical cliffs on the western escarpment are not over 20 or 30 feet high, below which the slope to the valley is comparatively gentle. The hillside is in many places thickly strewn with enormous boulders of granite, which have been moved by the glaciers from the adjacent cliffs. The principal outcrop is found on Sec. 22, T. 30, R. 7 E., where the Granite Heights and New Hill O'Fair quarries are located.

HISTORY OF THE DEVELOPMENT.

The value of the Wausau granite was first recognized by L. S. Cohn in 1874–75, while exploring the natural resources of that region. Samples were sent, at that time, to Mott & Co., of Joliet, Ill., who reported that "the material was too handsome when polished to bear out the possibilty of finding much of a ledge." When the railroad had reached the Heights in 1880 openings were made at several places along the bluff east of the river, revealing the presence of gray, as well as several different shades of red granite. Soon after these openings were made, Groth & Peters, of Wausau, leased the one at the extreme north and operated it for building stone and paving blocks, mainly the latter. This company employed a hundred or more men during several seasons, until the demand for paving blocks from the large cities was well supplied. In 1884,

the Cohn & Robertson Mfg. Co. opened a new quarry south of the one above mentioned, and in 1896 a third opening was made by L. S. Cohn. The first monument was built by the Cohn & Robertson Mfg. Co., in 1885. At the present time monuments constructed from this stone may be found in cemeteries all over the northwest.

The Granite Heights quarry, operated by Anderson Bros. & Johnson, was opened on property owned by August Kickbush & Son, in 1895, and is worked from April to November of each year. The quarrying operations have thus far been confined to large boulders. The New Hill O'Fair quarry, owned and operated by Olson & Magnesun, is adjacent to the Kickbush property, and produces essentially the same granite. It was opened in 1896.

At the present time four companies are operating in the Wausau granite. The Cohn & Robertson Mfg. Co. and the Fred DeVoe Granite Co. are operating the quarries of the L. S. Cohn Granite Co., on the east side of the river. On the west side of the river the New Hill O'Fair quarry is operated by Olson & Magnesun, and the quarry of August Kickbush & Son is operated by Anderson Bros. & Johnson.

QUARRY OBSERVATIONS.

The color of the granite over this extensive area is not uniform, but varies from gray through reddish brown to brilliant red.

The several openings on the east side of the river produce three shades of red, or reddish brown, and a gray. The granite which is quarried on the west side is mainly the bright red variety. The individuals composing the granite do not differ greatly in size in the different localities, being ordinarily of medium size. In most parts of the area the granite is massive, but in several instances a more or less schistose structure has been developed.

The granite, which in many places has been exposed to the weather for a very long time, shows very little disintegration at the surface, which is evidence of its durability. The

weathered surface has either a pinkish white, gray, or reddish brown color. The weathering is generally uniform, resulting in a comparatively even surface. In the outcrops east of the river the stone is often much broken up and discolored at the surface. In places, the quartz and feldspar individuals have been coated with iron oxide, staining and discoloring the granite in patches, to the depth of about 8 feet. The depth to which iron staining is ordinarily observed is much less, except along jointing planes, where the granite, on either side, is often discolored to a much greater depth.

Laboratory Examination.

The Dressed Sample.—The granite is well adapted to rock face work. The fracture is such as to give the work a moderate degree of prominence, harmonizing with either heavy or light constructional work. The hammered work is smooth and even, and ordinarily has a grayish red color. The granite is susceptible to a very high polish, possibly higher than that of any similar granite in the state, the bright red variety taking what is known as a water finish. The color varies from a gray to a brilliant red, depending on the color of the rock. The polished surface is given variety, in some of the quarried stone, by the recognizable schistosity, and the difference in the tint of red. The contrast between the polished and hammered surfaces is such that any lettering is brought out with perfect clearness, as shown in Plate LIX., Fig. 1, which was reproduced from a photograph of a specimen in the Survey laboratory, from Olson & Magnesun's quarry. The color and texture of the gray and brilliant red varieties are well shown in Plate XVI.

The gray granite is quarried only on the L. S. Cohn property, east of the river. This stone has not yet been placed on the market, but the examination of the polished specimen gives evidence of a stone equally well adapted to fine finished work as the red granite. The contrast between the hammered and polished surfaces is not as great as in the red varieties, and any lettering will be correspondingly less distinct.

WAUSAU GRANITE.

1. Citizen's National Bank, Stevens Point, Wis.

2 Marathon County Bank, Wausau, Wis.

Microscopical Examination.—An examination of a number of thin sections under the microscope shows that the rock is composed mainly of feldspar and quartz, with a very little biotite and hornblende. The grains are of medium and comparatively uniform size. Feldspar is the most abundant constituent, composing about three-fourths of the entire rock. The color of the red varieties is mainly due to the abundant red and flesh colored feldspars. The color of the gray variety is the result of a combination of white feldspar, dark mica, and hornblende. But even the gray granite contains an occasional pink colored feldspar, which gives the faintest tinge of pink to the rock. The feldspar individuals have very irregular outlines, and interlock, in an intricate manner, with the adjacent minerals of the groundmass. The feldspar consists of orthoclase, microcline, and plagioclase, but the former largely predominates. Intergrowths of two feldspar varieties and twinning of single varieties, are of common occurrence. As seen in ordinary light, the feldspar has a dirty color, although it is usually but little altered. The quartz is similar in outline to the feldspar, and interlocks in the same complex fashion. Strain shadows are very marked. The quartz is clear and translucent. Both the quartz and feldspar individuals have been somewhat granulated about their margins. Fractures in the rock have been sealed with veins of secondary quartz and, occasionally, feldspar.

Biotite is a more abundant constituent of the gray, than the red granite, being present in small flakes uniformly distributed through the rock. Hornblende occurs in relatively small individuals in both the red and gray varieties, but it is not abundant in either. Iron oxide, in the form of hematite and magnetite, is present in all the varieties. The magnetite occurs in irregular patches, often partly altered to hematite. The rusty brown color of the granite near the surface is largely due to the weathering of the magnetite. The hematite occurs in both the red and brown varieties. The former occurs in the fresh rock, while the latter is found mainly in the weathered portions.

The composition, texture, and kind of mineral constituents are shown in the microphotograph, Plate LX., Fig. 2.

Chemical Analysis.—The chemical analysis of a sample from Anderson Bros. & Johnson's quarry, west of the river, by Prof. W. W. Daniells, gives the following composition:

$Si\ O_2$	76.54
$Al_2\ O_3$	13.82
$Fe_2\ O_3$	1.62
$Fe\ O$	..
$Ca\ O$	0.85
$Mg\ O$	0.01
$K_2\ O$	2.31
$Na_2\ O$	4.32
$H_2\ O$	.20
	99.67

Physical Tests.—The specific gravity of the granite, as shown by determinations made on specimens from the quarries on both sides of the river, is practically uniform, averaging 2.63. (See Chapter VIII., Table V.) This is somewhat less than the specific gravity of the other Wisconsin granites, but it only indicates the absence of the less durable ferruginous minerals. The porosity of the sample tested from Olson & Magnesun's quarry was .379%. The two specimens from Anderson Bros. & Johnson's quarry had an average porosity of .42% The sample from L. S. Cohn's quarry gave an average porosity of .18%. Thus it appears that the porosity of these samples is uniformly very low, and the probability is that the size of the pores are correspondingly small.

Samples were placed in a muffle furnace, and heated to a temperature of 1200° or 1400° F. At a temperature of 1000° the specimens were but little injured. One of the samples was rapidly cooled from a temperature of 1200° to 1500°, which caused the corners to flake off. (See Plate LVII., Fig. 1.) The others were allowed to cool gradually, and there was but little external evidence of injury. Close examination and testing, however, showed that the strength of the rock was largely gone. Due to the extreme heat, the color of the rock

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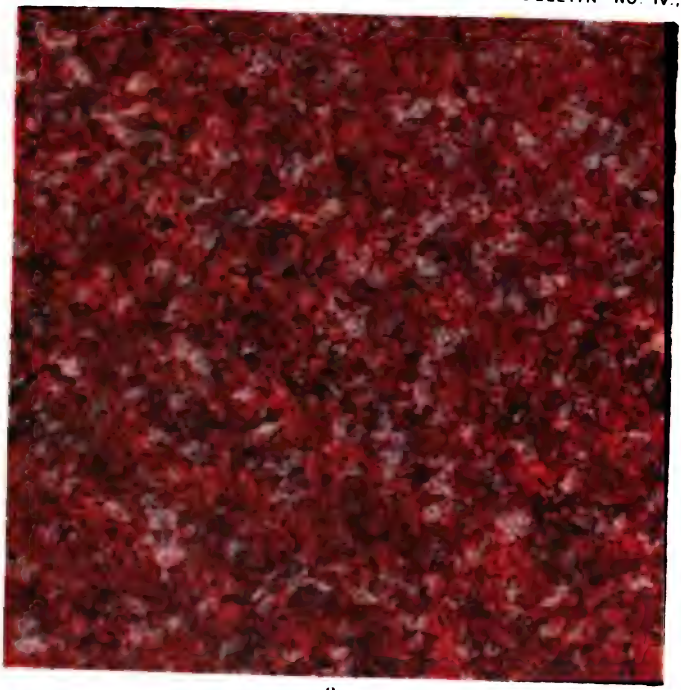

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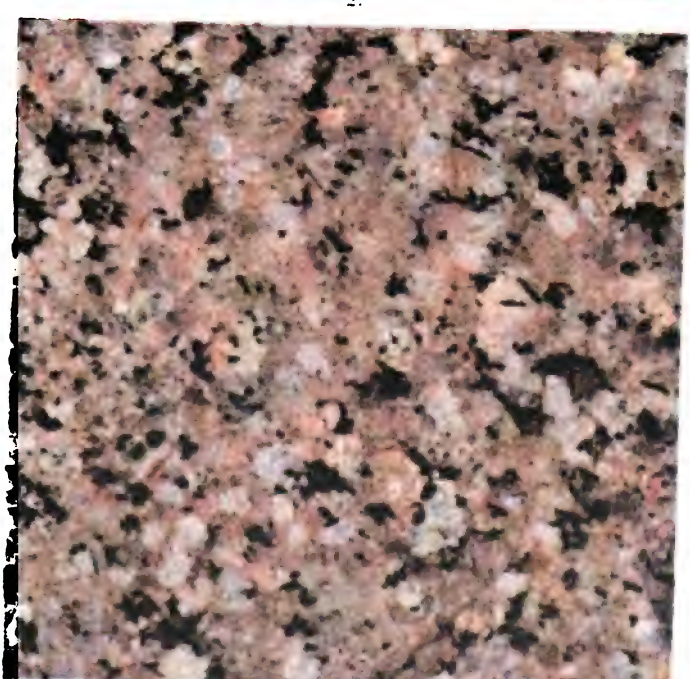


1. RED WAUSAU GRANITE. 2. GRAY WAUSAU GRANITE.

was changed after cooling to a pinkish gray. (See Chapter VIII., Table X.)

Samples from the quarries west of the river were tested to determine the effects of alternate freezing and thawing. Reference to Chapter VIII., Table VI., shows that the sample from Olson & Magnesun's quarry lost .12 of a gram in weight, after the 35 days' exposure, and that the two samples from Anderson Bros. & Johnson's quarry experienced an average loss in weight of only .08 of a gram. After determining the loss in weight, these samples were placed in the crushing machine to ascertain the loss in crushing strength. Chapter VIII., Table VII., gives the comparative strength of the frozen and fresh samples, and shows that the frozen sample from Olson & Magnesun's quarry tested 7,894 lbs. per sq. inch less than the fresh one. The frozen samples from Anderson Bros. & Johnson's quarry tested on an average of 2,201 lbs. per sq. in. less. The low crushing strength of the frozen cube from Olson & Magnesun's quarry was, at least, partly due to its imperfect shape.

The compressive strength of the granite was determined by crushing two inch cubes from each of the three quarries. The results are given in Chapter VIII., Table II. It will be observed that the average crushing strength of the granite from Anderson Bros. & Johnson's quarry is 22,507 lbs. per sq. inch, which is above the average for granite. The crushing strength of the granite from Olson & Magnesun's quarry is 27,200 lbs. per sq. inch, which corresponds very closely with that obtained for the samples from Anderson Bros. & Johnson's quarry. The average crushing strength of three samples from L. S. Cohn's quarry was 22,575 lbs. per sq. in.

The transverse tests, made upon small rectangular pieces, gave an average modulus of rupture of 2,518.5 lbs. per sq. inch. (See Chapter VIII., Table III.) This result is much higher than is required of stone used for the heaviest constructional purposes, and demonstrates the suitability of the stone for use in positions where a relatively high transverse strength is demanded.

Description of Individual Quarries.

In the following descriptions, the accessibility of the stone, and the conditions and facilities for quarrying at the individual quarries are considered.

THE L. S. COHN GRANITE CO.'S QUARRIES.

It has been previously stated that the L. S. Cohn quarries consist of three separate openings, each of which has been worked quite extensively at different times. They are located immediately adjacent to the C., M. & St. P. Ry., at the Heights station. The slope of the hill, which rises to an elevation of about 200 feet above the railroad, is strewn with angular fragments of granite of various dimensions. The principal outcrops are at the ends of the hill or near the summit, but by clearing away the boulders and angular fragments the solid granite may be reached at a very little depth on almost any part of the slope. The maximum stripping at any place on the slope apparently does not exceed 15 or 20 feet, the average being probably not over 6 or 8 feet. The granite, at all the cpenings thus far made, is somewhat altered and discolored to a depth of several feet below the surface. To this depth the quartz grains are mainly coated with a thin film of iron oxide, which imparts a dirty brown color to the stone. This discoloration by iron oxide is also very noticeable adjacent to the jointing planes, where it sometimes extends a considerable distance into the rock on either side of the wall. Besides these stainings, black streaks occasionally occur in the rock.

The main set of joints at the most northern opening strike N. 40–45° E. The second set strikes N. 30° W., and dips about 70° NE. A third set of joints are almost horizontal, forming the floor of the quarry opening. Two zones of close fracturing traverse the quarry parallel to the second set of joints.

The opening farthest south, from which the largest amount of stone has been quarried, was abandoned several years ago.

The reasons for this were, first, the heavy stripping, which is about 15 feet thick; second, several large greenstone dikes have been reached, beyond which it is quite certain that for some distance the stone is badly broken up. The largest of these dikes now forms the main part of the back wall. The granite which was removed in front of it was more broken up than elsewhere, and small stringers of greenstone filled many of the cracks immediately adjacent. It would be necessary to open the quarry some distance beyond the dike before large dimension stone, free from the black greenstone stringers, could be obtained. A second small dike, striking north and south, is found directly east of the large one. Apparently the strike of these dikes coincides with the major jointing planes observed in the other openings.

The average height of the face at this place is about 22 feet. The joints are essentially the same as those occurring at the other openings. The wall adjacent to the larger greenstone dike, corresponding with one set of joints, strikes about N. 10° W. A second set of joints strikes at about right angles to the first set, or nearly east and west. Two minor sets of joints occur at this opening, which correspond very nearly to those of the previously described opening. These joints strike respectively N. 35° W. and N. 45° E. The first set is almost vertical, but the latter set is inclined about 18° from the vertical. A zone of close fracturing traverses this opening in an NE.–SW. direction, corresponding in general to the second minor set of joints. The joints, which strike east and west and north and south, average about 4 feet apart, but in many instances they are much closer, on account of which it is difficult to obtain stone of large dimensions.

The color of the granite sometimes varies in different parts of the same opening, being darker colored in some portions than in others. Where absolute uniformity of color for monumental or constructional work is desired, care should be exercised to select material in which the colors are not mixed.

A considerable amount of excellent stock has been quarried from the large boulders and angular fragments covering the

side of the hill, which are, as a rule, No. 1 stone, and in all respects as desirable as the stone quarried from the ledges.

The company is well equipped with derricks, tracks, dummy cars, and complete polishing works. Nevertheless, as now conducted, the quarrying is manifestly expensive. The derricks are operated by hand, and the cars which carry the stone to the yard are hauled up the hill, and back to the quarry, by hand. More improved methods of quarrying are necessary if the work is to be conducted economically. The average value of the stone is about $1.00 per cu. ft.

THE NEW HILL O'FAIR QUARRY.

The quarry nearest to the railroad on the west side of the river is the one owned and operated by Olson & Magnesun. The stone is quarried mainly from very large fragments of granite which cover the 15 acres of land owned by this firm. The granite is apparently all of one color, a very brilliant red. Almost any dimensions from 1 to 20 feet can be obtained from these blocks. The granite is suitable either for monumental or building purposes, but is now used exclusively for the former. The sample of stone from this quarry, which is on exhibition in the laboratory of the Survey, gives an excellent idea of the monumental work which is being done by this firm. Plate LIX., Fig. 1, is taken from a photograph of this sample, and shows nicely the contrast between the hammered and polished surfaces.

THE GRANITE HEIGHTS CO.'S QUARRY.

The quarry which is operated by Anderson Bros. & Johnson, and owned by Kickbush & Son, is adjacent to the New Hill O'Fair quarry. As in the previous quarry, the stone which has been thus far quarried has been taken entirely from the boulders or fragments covering the side of the hill near the natural outcrops. No attempt has yet been made to quarry from the ledge because blocks of any desired dimensions can be easily obtained from the boulders or fragments

1. C., M. & St. P. Ry. Depot, Oconomowoc, Wis.—GLACIAL BOULDERS.
2. Marathon County Court House, Wausau, Wis.—WAUSAU GRANITE.

mentioned above. A perfect boulder, without a detectable seam, was measured at this place, and found to be 15 ft. by 19 ft. by 4 ft. The supply of stone, of any ordinary dimensions, is practically unlimited. The boulders will undoubtedly be used for some time, as the cost of quarrying is less than from the natural outcrop. The height of the exposed cliff above the talus slope is about 30 feet, and extends along the hill for a distance of about 200 yards. There is a steep talus for a considerable distance below the cliff, which would be expensive to remove; but the face not covered with talus is sufficiently large to make an excellent quarry opening.

The stone is the brilliant red variety, and is used exclusively for monumental purposes, being equal in all respects to that which is obtained from Olson & Magnesun's quarry. The sap nowhere exceeds two inches in depth, and the stone is essentially free from veins or other discolorations. In some instances the granite is slightly schistose, but this structure is not sufficiently pronounced to detract from its salability. The greatest drawback to the successful operation of these quarries, on the west side of the river, is the distance of a mile and a quarter which the quarrymen are required to haul their stock to the nearest railway station. Further, owing to the fact that there is no bridge across the river, the teaming at this point must be done in the winter, when the river is frozen. The cost of hauling the stone from the quarry is about three cents per cubic foot, which is sufficient to exclude it from the building stone market.

Statistical Data.

Amount of capital invested: $3.000.00

Facilities at hand for quarrying: 1-1 hp. engine, 1 hand derrick, 3 polishing machines.

Average number of employees: 13.

Wages paid different classes of employees:

Stone cutters	$3.00
Quarrymen	1.75
Polishers	1.70

Cost of cutting and dressing per square foot:

Pointed	$ .40
Ax-hammered	.50
Bush-hammered or chiseled	.90
Polished	1.00

Average value per cubic foot:

Rough stock	$1.00

General Considerations.

In general, the examination of the stone in the quarry, combined with the laboratory tests, substantiate the claims of the operators that the granite is in all respects well suited for monumental, ornamental, and constructional purposes.

AMBERG AREA.

One of the most extensive granite areas in Wisconsin is located in the vicinity of Amberg, Marinette county, in the northeastern part of the state. (See Plate III.) This section of the state is remarkable, not only for the abundance of granite, but also for the great variety in texture and color. Hundreds of acres of workable granite are found in this section of the state. Not all of it is so situated as to insure profitable quarrying, but at many points, and especially where quarries are now located, the opportunities are exceptionally favorable. The C., M. & St. P. railroad penetrates the heart of this region, and furnishes excellent facilities for transportation to all the important markets of the northwest.

The center of the granite industry is, at the present time, located on the Pike river, at Amberg, a town on the C., M. & St. P. railroad, near the center of T. 35, R. 20 E. The Argyle and Aberdeen quarries of the Amberg Granite Co. and the quarries of the Pike River Granite Co., as well as the extensive works of the Amberg Granite Co., and those of the Pike River Granite Co., are located at this place. The Athelstane, the most extensive quarry of the Amberg Co., is located about nine miles south west of Amberg, in the north-central part of T. 34,

R. 9 E., on a spur of the C., M. & St. P. railroad. The station at that place bears the same name as the quarry.

Only two of the four quarries above mentioned are now being extensively worked. One is the Athelstane, of the Amberg Co., and the other is the quarry of the Pike River Granite Co. The former is being worked almost exclusively for building purposes, while the latter furnishes stone mainly for monumental work.

From the four quarries, three distinctly different colored granites are obtained. The granite which has been quarried from the Argyle and that which is taken from the main opening of the Pike River Granite Co. have a gray color and are essentially fine grained. That which is quarried from the second opening of the Pike River Granite Co., and that which is taken from the Aberdeen quarry, are very nearly alike, being coarse grained, red granites, ordinarily known as the "Amberg red." The granite quarried from the Athelstane quarry is very similar to the Amberg red in texture, but the color, instead of being red, is gray. The two are probably different phases of the same granite, in one of which the feldspar has a white and light brown color, while in the other the color of the feldspar is mainly pink.

FINE GRAINED GRAY GRANITE.

Quarry Observations.

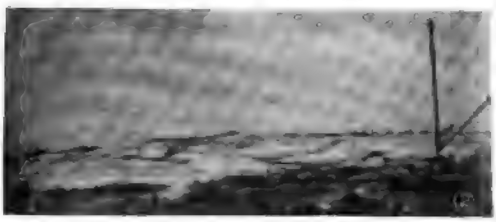
The fine grained gray granite from the Argyle and Pike River quarries is similar in many respects to that which is imported from Scotland and the New England states. A careful examination of the weathered surface, in the natural exposure, shows that the sap does not extend to a maximum depth of more than three inches, and that the average depth is less than one inch, often being not more than one-eighth of an inch along vertical jointing planes. The color of the weathered surface is a quite uniform grayish white. In both quarries, the granite has a slight rift, which can only be detected when the stone is being worked. The color and texture of the granite from these quarries are essentially the same.

Laboratory Examination.

The Dressed Sample.—Plate XX., Fig. 2, is an identical reproduction of a portion of the polished face of the sample in the laboratory of the Survey. The polished surface has a slightly iridescent sheen, which is possessed by but few granites of this color. The finish, which the polished surface takes, is superior to that of many of the imported gray granites, which have won such favor among the people of this and adjacent states. The rock face and hammer dressed surfaces are both very excellent. One of the admirable features of this granite is the excellent contrast between the hammered and polished work. The hammered work is almost white, while in sharp contrast to this, the polished surface is decidedly gray.

The difficulty which is often experienced in bringing out with distinctness the lettering, on eastern gray granites, is not met with in working this granite. Carl Manthey, a prominent monument manufacturer of Green Bay, says that every monument which he has erected out of this granite has given entire satisfaction. He says that the contrast between the hammered and polished surfaces is not equalled by that of any other gray granite on the market, and that he can recommend none higher than the Pike River Granite. With many granites it is necessary to paint the letters in order that they may stand out bold enough to be easily read. Such a thing is unheard of in connection with the Pike River Granite.

Microscopical Examination.—The mineralogical composition of the gray granite, as shown by the microscopical examination of the thin section, is mainly feldspar and quartz, the former of which makes up more than one-half the entire rock. Quartz is next in abundance to the feldspar, and constitutes a large part of the remainder. Biotite is a much less abundant costituent than either, but is scattered in small flakes quite uniformly through the entire rock. The quartz and feldspar individuals vary quite largely in size, and interlock in a very complicated manner. The feldspar is mainly of the orthoclase and mi-



ATHELSTANE GRANITE.

1. Portion of the old Quarry.

2. The new Quarry.

crocline varieties. Twinning is common, and intergrowths of two varieties are of frequent occurrence. Certain of the feldspar individuals are clear and fresh, but many of them are cloudy showing some evidence of alteration. The quartz individuals are more regular in outline than the feldspar, and are clear and translucent. Both the quartz and feldspar individuals show strain shadows and granulation. Certain of the longer feldspar individuals have also been bent. The biotite occurs either in clusters of tabules or disseminated, as isolated individuals, through the section. Zircon, and a number of less important minerals, constitute the accessory constituents. The texture and composition of the granite are shown in the microphotographic reproduction. (See Plate LXII., Fig. 1.)

Physical Tests.—The specific gravity of the gray granite, as determined from specimens taken from the quarry of the Pike River Granite Co., is 2.685, which is above the average for the granites tested in the preparation of this report. The porosity of the granite was determined to be .251%, which is below the average for the granites tested. There was no loss in weight due to alternate freezing and thawing, but the crushing strength of the frozen sample was 9,448 lbs. per sq. in. less than that of the fresh sample. (See Chapter VIII., Table VII. The crushing strength of the fresh sample, given in table II., of the same chapter, is 27,887 lbs. per sq. in. The reason that the frozen sample gave a crushing strength so much lower than the fresh one may be partly due to the imperfect shape of the cube.

The results of these various tests are entirely satisfactory, showing beyond a doubt that perfect blocks of this granite, free from seams, are equal, if not superior, to any other gray granite used in this or adjacent states.

AMBERG RED GRANITE.

Quarry Observations.

The Amberg red granite, which is obtained from the Aberdeen and Pike River quarries, is a coarse grained rock, in which the color is far from a decided red, when compared with

the Wausau granite. It might more appropriately be called a pale pink. The texture and color of the granite in the natural exposures are generally uniform. The weathered surface is comparatively smooth and even, showing only very minute depressions, where the more readily disintegrated biotite has been carried away.

Laboratory Examination.

The Dressed Sample.—A close examination of the hand specimen shows that the color of the feldspar individuals is mainly a pinkish red, which gives to the rock a pale pink color. The granite is susceptible to a very good finish, although the contrast in color between the hammered and polished work is not as striking as in the gray previously described.

Microscopical Examination.—The microscopical examination shows that the individuals are very large and interlock in an intricate manner. Feldspar is the preponderant constituent, although quartz is more abundant than in the previously described granite. The feldspar consists mainly of orthoclase and microcline, showing intergrowths and twinning. Most of it is clear and fresh, although a few of the larger individuals are partly altered to epidote. The quartz is clear and transluscent. Both the quartz and feldspar individuals show strain shadows and peripheral granulation, resulting from mechanical stresses in the rock. Biotite is a subordinate constituent and is present mainly in irregular plates of considerable size. An interesting occurrence of rectangular fracturing of the biotite, which is now filled with quartz, was observed in this section.

Physical Tests.—Two samples of red granite from the Pike River Granite Co.'s quarry were found to have an average specific gravity of 2.658, and a porosity of .25 per cent. (See Chapter VIII., Table V.) Alternate freezing and thawing occasioned a loss in weight of .05 of a gram on a mass weighing 371.-65 grams. This difference in weight is no more than might be in-

WORKS OF THE AMBERG GRANITE CO., AMBERG, WIS.

1. Interior View. 2. Exterior View.

cident to manipulation, and has little or no significance. The crushing strength of the frozen sample was 4,208 lbs. per sq. in. more than that of the fresh sample, as indicated in Chapter VIII., Table VII. The crushing strength of the fresh sample is given in the same table, and is 18,273 lbs. per sq. in. This difference in strength is accounted for, as in the samples of gray granite, by the irregular shape of the sample. From these tests it would appear that the granite was suitable, in point of durability and strength, for either constructional or monumental purposes.

ATHELSTANE GRANITE.

Quarry Observations.

The coarse gray granite which is quarried exclusively by the Amberg Granite Co. from the Athelstane quarry, has essentially the same texture and composition as the red granite just described. The only difference between the red and gray varieties is in the color of the feldspars, which, in the Athelstane, is white and brownish gray, and, in the red granite, pinkish red.

The color of the weathered surface of the granite is white with a very faint pinkish tone. Glacial groovings are still to be made out on the surface of many of the natural exposures which give evidence of the durability of the granite. The surface of the natural exposures is somewhat rough, due to differential weathering of the mineral constituents. An abundance of lichens grow upon the surface, indicative of general durability. The first five and a half feet below the surface is stained more or less brown, through the weathering of the feldspar. Adjacent to many of the jointing planes the same discoloration occurs, penetrating the rock on either side to a depth of several inches.

Laboratory Examination.

The Dressed Sample.—The specimen in the laboratory of the Survey illustrates the excellent dress which the stone is

capable of taking. The rock face is bold and rough, being well suited for heavy masonry construction. The dress of the 6, 8, and 10 cut faces is superior to that of most coarse grained granites. The hammered face has a general gray color, spotted quite uniformly with dark patches of hornblende and biotite. In striking contrast with this is the brilliant bluish gray color of the polished surface, which is so well reproduced on the accompanying plate. (Plate XX., Fig. 1.)

Microscopical Examination.—Feldspar is the preponderant constituent. Quartz is next in abundance, while biotite and hornblende, although present in relatively large quantities, are least abundant. Hornblende is more abundant than biotite. The individuals correspond very closely in size and arrangement with those of the red granite, and show strain effects and peripheral granulation, as previously described. The kind of minerals and their arrangement may be seen in the accompanying microphotograph. (See Plate LXII., Fig. 2.)

Chemical Analysis.—The following is a chemical analysis of the Athelstane granite, made by Prof. W. W. Daniells:

SiO_2	66.10
Al_2O_3	20.82
Fe_2O_3	1.52
FeO	2.17
CaO	1.57
MgO	0.95
K_2O	3.48
Na_2O	2.94
H_2O	0.54
	100.09

Physical Tests.—The results of the strength and durability tests are given in the tables in Chapter VIII. The average specific gravity, as recorded in Table V. of the same chapter, is about 2.706, which is somewhat higher than that obtained for the other granites of Wisconsin. This is largely due to the hornblende, which is an important constituent of the granite. The average percentage of pore space, or porosity, is very low, being about .22 of 1 per cent.

Samples were gradually heated in a muffle furnace to a temperature of 1200° to 1500° F. Sudden cooling of the stone shattered it throughout. (See Plate LVI.) At 1000°–1200° F. the stone was, to all appearances, little injured.

The freezing and thawing tests resulted in an average loss in weight of .09 of a gram on a mass of about 352 grams. The decrease in strength resulting from alternate freezing and thawing, is given in Chapter VIII., Table VII. This difference of 9,369 lbs. per sq. inch is somewhat above the average, and indicates that the rock is more susceptible to injury from frost than other granites, differently constructed.

The average crushing strength of the granite is nearly 20,000 lbs. per sq. in. (See Chapter VIII., Table II.), which is about the average strength of ordinary granite.

Description of the Individual Quarries.

THE PIKE RIVER GRANITE CO.

The Pike River Granite Co. was organized in February, 1896. The quarry is located about half a mile northeast of the station, at Amberg, and consists of two openings. The main opening is the one from which the gray granite is quarried, and is situated on one of the many granite mounds in this area, having an elevation of from ten to fifty feet. The size of the opening, when visited in the summer of 1897, was about 65 ft. by 20 ft. by 15 ft., indicating that a considerable amount of stock has been quarried during the eighteen months that the company has been operating. Four sets of joints break the rock into polygonal blocks of various dimensions. The most prominent of these sets strike N. 70° W. and N. 30° E. The two less conspicuous sets strike N. 15° W. and N. 28° E. The floor of the quarry is formed by a jointing plane which dips at an angle of about 45°, and strikes about east and west. The granite has an imperfectly developed rift, which is only noticeable when the stone is being worked. The size of the blocks that can be obtained varies greatly, depending upon the closeness of the joints. Incipient joints are a source of some annoyance, and

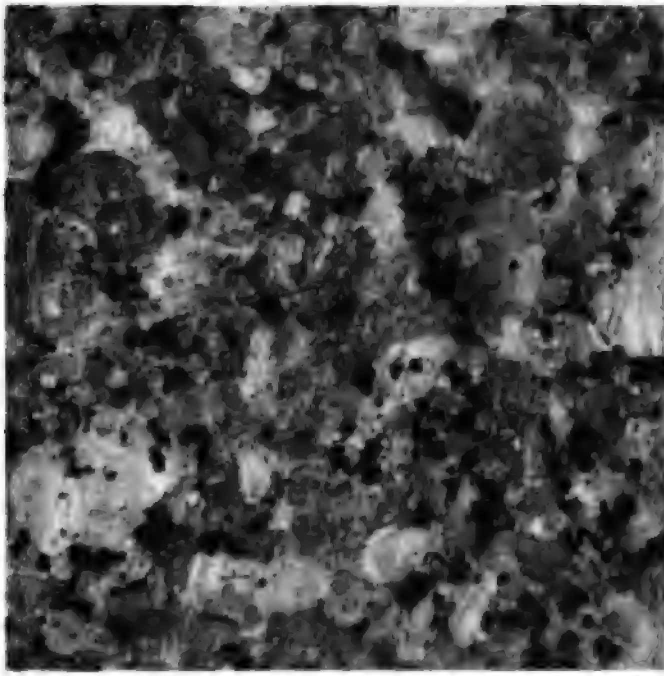
the quarrymen have to keep constantly on the alert to guard against them. In places the joints are as much as 10 feet apart, and dimensions large enough for most monumental work can be obtained.

The second opening of the Pike River Co. is in the Amberg Red granite, south of the one just described. This quarry has not been worked very largely, the demand being mainly for the gray variety, from the other quarry. The joints in this quarry strike N. 85° W., and N. 40° E. There is a natural face about 11 ft. 8 in. high, corresponding to the first set of joints. The floor dips slightly to the south. Blocks as large as 11 ft. by 10 ft. by 6 ft. can be obtained, although smaller dimensions are more abundant.

The Pike River Granite Co. is composed of practical stone cutters, each one of whom has had long experience in the granite cutting business. The company is equipped with necessary tools and derricks for handling the stone in the quarry, and has erected a polishing mill fitted for turning out every grade of work. The company sells stock in the rough or makes monuments to order. They are also prepared to furnish stone for building purposes.

During the first ten months that the company was in operation the output was valued at $4,000.00, a large part of it being rough stock. The present markets for the stone are the middle, western, and northwestern states. Since the Amberg company ceased working the Argyle quarry, this is the only company in the northwest that is known to be quarrying a fine grained gray granite. The demand for this color and quality of granite is very large, and there seems little doubt but that the success of the quarry is assured. The granite is, in every respect, as durable and strong as the best eastern or imported fine grained gray granites, and sooner or later it will be largely substituted for them, in this and neighboring states, as a monumental stone.

1.



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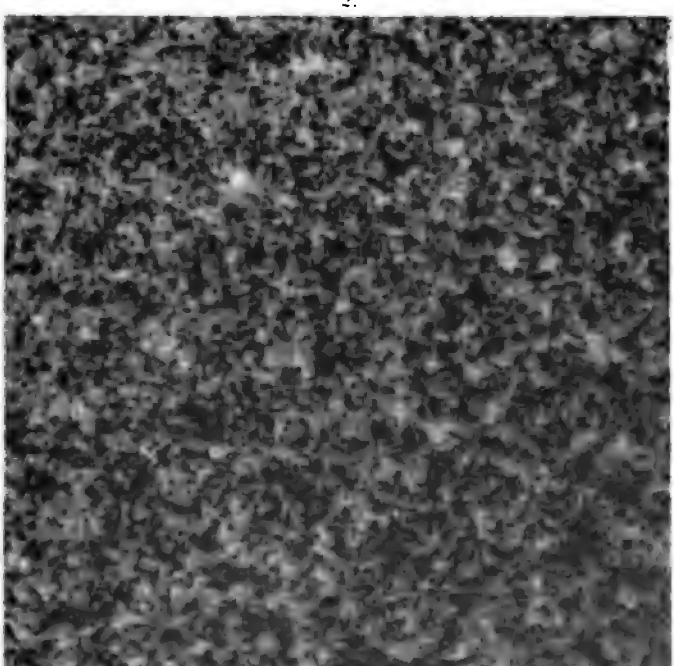


1. ATHELSTANE GRAY GRANITE. 2. GRANITE. PIKE RIVER GRANITE CO.

Statistical Data.

Amount of capital invested: $3,000.00

In operation only 10 months. Output was valued at $4,000.00.

Facilities at hand for quarrying: 1 20-hp. engine. 1 derrick. Polishing mill.

Average number of employees: 12 to 16.

Wages paid different classes of employees: $1.75 to $3.25.

Average value of each grade per cubic foot: $1.00.

AMBERG GRANITE CO.

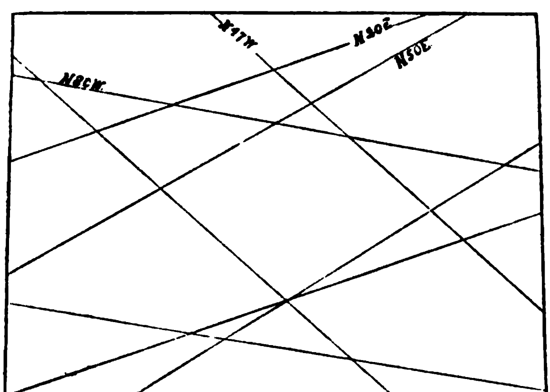
The Amberg Granite Co. is perhaps the most extensive granite company in the northwest, and is the best equipped for furnishing stone for heavy constructional work. The company has an invested capital of $200,000.00, and owns a thousand acres of land adjacent to Amberg, much of which has excellent granite. Since the quarries were first opened, they have been worked almost continuously. The Argyle and Aberdeen quarries were opened first, and large amounts of stone were sold for paving, building, and monumental purposes. Later the Athelstane was opened, the stock being used almost exclusively for building.

The Argyle Quarry.—The stone quarried from the Argyle quarry, some distance north of the station and adjacent to the railroad, is fine grained gray granite, similar to that quarried by the Pike River Granite Co. The main difficulty experienced in quarrying this stone is the inability to obtain large dimensions of clear stock, free from seams. At one time paving blocks and monuments were very largely manufactured, but since the company has turned its attention exclusively to constructional work, this quarry has been abandoned. Some very pretty buildings and numerous monuments have been constructed from the Argyle granite. One of the buildings is shown in Plate XXI. Of course, as may be seen, this building has been constructed out of small sized blocks, but the appearance nevertheless is very pleasing.

The Aberdeen Quarry.—This is the quarry owned by the Amberg Granite Co. from which the Amberg red granite is

obtained. It is situated on the railroad, a short distance south of the station, and so close to the tracks, that blocks from parts of the quarry can be swung by a single derrick directly onto the cars. The opening is irregular, extending in one place 200 or more feet back from the tracks. Each of two sides of the quarry has a working face of about 200 feet. The north face is about 25–35 ft. high.

The joints strike about N. 20° E., N. 50° E., N. 47° W., and N. 80° W., the first three sets being best developed. The joints are mainly vertical, and show on the surface as a series of diagonally intersecting lines, about as represented in the accompanying illustration. (See Fig. 2.) These joints are all the way from 1 to 10 feet apart and break the stone into polygonal blocks of many different dimensions.



JOINTING AS IT OCCURS IN THE ABERDEEN QUARRY.

FIG. 2.

The exposures immediately adjacent to the quarry are cut by very many dikes of fine grained granite, coarse pegmatite and greenstone. In parts of the quarry the greenstone dikes appear much like inclusions, but on close inspection this is found to be due to faulting.

The Aberdeen quarry is not operated at present, although a large amount of stone has been quarried in the past years. The

expense of quarrying this stone for heavy constructional purposes was so much more than that of the Athelstane, on account of the difficulty in securing suitably large dimensions, that it has been abandoned. For light building and monumental work it is thought that portions of the quarry might still be worked to good advantage.

The Athelstane Quarry.—This is the main quarry of the Amberg Co., and is situated at Athelstane about nine miles southwest of Amberg. The quarry was opened in 1892, and has been operated each year since. Two openings have been made on two low mounds of granite rising about 30 feet above the general level of the country. At either place the supply of granite is practically unlimited. The old opening, as it is called, is about 200 feet long, 100 ft. wide, and 24 ft. deep. The new opening is 150 ft. long, 20 ft. wide, and 14 ft. deep. (See Plate XVIII.) During the last four years, up to 1897, this quarry furnished about 58,000 cubic feet of stock, mainly for building purposes.

The stripping is practically nothing over the entire area, the mounds on which the quarries are located being almost entirely bare. The main set of joints in the old opening are about 4–12 ft. apart, and strike N. 24–28–33° W., there being a slight variation in different parts of the quarry. This set of joints is closer than any of the others in the quarry, and, by measurement the planes were found to occur the following distances apart:

9	ft.	4	in.
4	"	8	"
9	"	6	"
7	"	8	"
11	"	6	"
8	"	0	"
10	"	0	"

The second set, which strikes N. 28° E., is not very important. Another set, striking N. 68° W., is still less prominent. The floor is uneven, and the nearly horizontal joints divide the 26

foot face, at the middle, into the following thicknesses, from the top to the bottom:

1	ft.	6	in.
3	"	2	"
0	"	10	"
2	"	1	"
0	"	10	"
2	"	8	"
15	"	0	"

The last bed which contains the best stock in this opening splits into two benches, 7 ft. 3 in. and 7 ft. 9 in. in thickness.

The jointing in the new opening is essentially the same as in the old. On the surface it appears that even larger dimensions can be quarried than at the old quarry. Blocks weighing 50 tons have already been quarried at this place.

The company is prepared to furnish building stone of any desired dimensions. The great advantage which this quarry presents over many others is the facility with which blocks of large dimensions can be quarried. Large dimensions are always at hand, and when a block is quarried it is generally sound and free from incipient joints. A few small pegmatitic veins, three or four inches wide, cut the old opening in various directions, but they are of such infrequent occurrence as to injure the stock but very little.

The Athelstane quarry is equipped with all necessary machinery for quarryng, including four engines, with an aggregate of 195-hp., two travelers, and three steam derricks.

The works of the Amberg Co., situated near the railroad station at Amberg, are the best equipped for turning out heavy constructional work of any in the northwest. The exterior and interior of the works are shown in Plate XIX. The equipment consists of turning lathes, polishing machinery, and planer for cutting granite. The planer used has special improvements made by the secretary of the company, Wm. R. Hinsdale, which place the machine far ahead of all others now on the market.

FINE GRAINED GRAY GRANITE, AMBERG, WIS.

Citizens' National Bank, Green Bay, Wis.

The markets for the granite cover a wide territory, from Pittsburg to Denver, and from St. Paul to New Orleans. A few of the structures into which the Athelstane granite has gone and the date of erection are as follows: Milwaukee Postoffice, 1893; St. Galls Church, Milwaukee, 1893; Park Bldg., Pittsburg, 1896; Cosmopolitan Hotel, New Orleans, 1894. Besides these the stone has been used in the construction of residences and mausoleums all over the country.

The company is prepared to furnish stone for all purposes for which granite is adaptable. Among these may be mentioned building, monumental, bridge, paving, and macadam. The extensive use of Bedford limestone has increased the demand for gray granite as trimming. For this purpose no granite can be found more suitable than the Athelstane.

General Considerations.

In general, the results of the laboratory tests of the granites from the Amberg area give sufficient evidence of their strength and durability, to warrant their use, not only in monuments and small buildings, but also in the heaviest kind of constructional work.

The Amberg Granite Co. is making a specialty of furnishing granite for constructional purposes, while the Pike River Granite Co. does almost exclusively a monumental business. The industry at this place has been very slow in recovering from the business depression of a few years ago, but the future is excellent for these, as well as all other quarries, where the stone is of good quality, and can be quarried with sufficient economy to compete with the granites of eastern and neighboring states.

Statistical Data. (Athelstane Quarry.)

Amount of capital invested: $200,000.00.

Shipments for the past four years:

1893	**30,000 cu. ft.**
1894	**10,000 cu. ft.**
1895	**10,000 cu. ft.**
1896	**8,000 cu. ft**

Facilities at hand for quarrying: 1 75 hp. and 3-40 hp. engines, 2 travelers, 3 steam derricks, planer, turning lathes, and polishing machinery.

Average number of employees: 25 to 250.

Wages paid different classes of employees:

Granite cutters	**$3.25**
Quarrymen	**2.00**
Laborers	**1.50**

Cost of cutting and dressing per square foot:

Pointed	**$ .30 to $ .40**
Bush-hammered or chiseled	**.50 to .75**
Polished	**1.50 to 1.75**

Cost of transportataion, by rail, $ .15 to $ .40 per cu. ft.

HIGH BRIDGE AREA.

A small quarry, owned by the French Granite Co., is located at High Bridge, a station on the Wisconsin Central Railroad, about 18 miles south of Ashland. The main interest in the quarry is held by. Wm. Gotchenberg of Ashland. Three openings, about 10 feet on a side and 8 feet deep, were made in 1892. A number of pieces of granite were variously dressed and polished and exhibited at the World's Columbian Exposition, in Chicago, in 1893, receiving very favorable comment.

The quarry is located at the end of a hill of considerable size, about a mile and a half south of the station. The face has a maximum depth of about 40 feet, and shows joints which strike N. 72° E., N. 50° W., and N. 55° E. The first two sets are essentially vertical, while the third dips at an angle of from 32 to 50 degrees. Zones of close jointing were observed, between which the seams are farther apart and good dimension stock can be quarried.

The granite from this quarry has a mixed pinkish gray color, which is quite uniform throughout the quarry. The rock has a porphyritic texture, in which the groundmass is composed of feldspar, quartz, biotite, and hornblende, and the phenocrysts are feldspar. The average porphyritic feldspar individuals are about one-half an inch long by one-fourth of an inch in cross section. The largest are about twice this size.

Laboratory Examination.

The Dressed Sample.—The polish which the granite takes is very good, and the color is similar to that of the natural surface. The hammered work also shows up very well in the specimen under observation.

Physical Tests.—The specific gravity is 2.672, which corresponds very closely with the specific gravity of the granite from Granite City. (See Chapter VIII., Table V.) The porosity, as given in the same table, is .65 per cent. The effect of alternate freezing and thawing is shown in Tables VI. and VII. It will be observed that the samples suffered no loss of weight, but that the crushing strength was about 8,000 lbs. per sq. inch less than that of the fresh sample. The crushing strength of the fresh granite is given in Table II., and is 24,229 lbs. per sq. in.

These tests are very satisfactory, showing very clearly the equality of this granite with other similar ones in this or neighboring states. The color and texture are different from any of the other Wisconsin granites, adding another to the already numerous varieties quarried in this state.

General Considerations.

The quarry is without equipment, and it is thought that unless operations were to be conducted on a scale sufficiently extensive to demand a railroad spur to the quarry it would be somewhat impracticable to operate at this place.

About a mile and a half farther south two other distinct kinds of granite outcrop in abundance, but the present inaccessibility of the place, owing to the distance from the railroad, precludes any possibility of their being operated for years to come.

IRMA AREA.

For a number of years there has been an attempt to develop a certain ledge of granite near the C., M. & St. P. Ry. at Irma, Lincoln county. The area was visited during the summer of

1897, and samples, prepared by the owner, Mr. O. J. Jenks, of Merrill, were tested in the Survey laboratory in the preparation of this report.

The granite has a schistose or laminated structure with a general pinkish gray color. It is thought to have originally been very similar to the Wausau granite, and may even be a part of that formation, in which there has been developed the schistose structure referred to.

Laboratory Examination.

The Dressed Sample.—The hammer dressed surface is almost white, furnishing a pleasing contrast with the pinkish gray of the polished face. The lettering is very distinct, as can be seen in the illustration. (See Plate LIX., Fig. 3.) The rock face has a very light pink color, and presents a moderately bold effect.

Microscopical Examination.—The mineral constituents, as revealed by the microscopical examination, are mainly, in the order of their relative abundance, feldspar, quartz, and biotite. The quartz and feldspar have been decidedly granulated, while the biotite individuals are arranged with their longer axes in a common direction. Due to this parallel arrangement of the biotite, the rock possesses the laminated or schistose structure above referred to.

Physical Tests.—Chapter VIII., Table V., gives the specific gravity and porosity of two samples of this granite. The average specific gravity is 2.646, and the average porosity .55 per cent. The specific gravity is about the average for granite, while the porosity is a little above the average.

The alternate freezing and thawing to which the cubes were subjected, resulted in an average loss for the two samples of .10 of a gram on a mass of about 370 grams. The frozen sample tested on an average of 2,259 lbs. per sq. inch less than the fresh ones. Among the granites subjected to extreme heat, that from Irma was, to all appearances, the least injured. At a temperature of 1200°–1500° F. the sample showed only two very small cracks at the margin. The color was changed to a very light

pink. The ring of the granite was clear and light, the same as that of the other granite samples tested.

The crushing strength of the fresh samples is given in Chapter VIII., Table II. The average of the results there recorded is 18,023 lbs. per sq. inch. The maximum result obtained was 22,690 lbs. per sq. inch.

General Considerations.

The above laboratory examination indicates that the granite comes well within the standard of strength and durability, being suited either for building or monumental work. There is some question as to whether the granite will take a desirable polish along the direction of the schistosity. The manner in which the stone occurs in the quarry does not afford one a very good basis to estimate the expense of quarrying. The outcrop is on the brow of a small knoll, and not sufficiently well exposed to make an estimate of the possible dimensions. The quarry is located about three-fourths of a mile from the railroad, and it would be necessary for successful operation to have a railroad spur from the main road to the quarry. This, of course, would not be practicable until the quarry has proved able to furnish large dimensional stock with a reasonable degree of facility.

MISCELLANEOUS AREAS.

Among the many areas of undeveloped granite within the state, it is difficult to indicate any few that should be given special attention. Fine grained gray granite is now quarried at a single locality. The demand for granite of this color is large and steady, and for this reason it may be well to mention that granite of this description occurs in the vicinity of the Falls of the Prairie river, and in the SE. ¼ of Sec. 26, T. 32, R. 7 E., and also probably in other localities which have not been brought to the attention of the author. The location of these ledges is not very favorable for transportation and they will probably remain undeveloped for many years.

At Black River Falls two different granites outcrop near the river, which might be profitably quarried for small dimen-

sional purposes. The property on which these granites occur is owned by the York Iron Co. and Mr. A. D. Merrill, of Merrillan. One of the granites is a fine grained stone, resembling very much, in color, the Montello granite. The exposures of this granite occur near the river, on the east bank, and are considerably broken up by numerous joints, precluding the possibility of quarrying very large blocks. Nevertheless, it is thought that the stone might furnish stock for a considerable variety of uses. The other granite, which outcrops near the old smelter and tracks, is a coarse red variety, which gives better indications in the way of obtaining large dimensions. At this place the stripping is about 15 feet. The joints strike about N. 78° E. and N. 12° W.

From Dexterville to Jenny Bull Falls, along the Yellow river, in Wood county, a great variety of igneous rocks, mainly granite and rhyolite, outcrop. At the Falls a coarse grained red granite, resembling that at Black River Falls, outcrops in abundance. The granite occurs in dimensions suitable either for building or monumental purposes, but, owing to the inaccessibility of the locality, the expense of opening a quarry at that place would be too great to warrant the undertaking.

There are many other areas in different parts of the state, where equally suitable granite may be found in large quantities. But so long as the cost of opening and lack of transportation facilities places the stone on the market at such a disadvantage with the stone from quarries where the facilities are better, they cannot be successfully developed.

PLEISTOCENE BOULDERS.

The boulder deposits scattered over a large part of the state are one of the important sources of igneous rocks, suitable for building purposes. At irregular intervals over most of the southern part of the state nests and trains of granite, rhyolite, and greenstone boulders have been deposited by the glaciers. During the glacial epochs, the ice transported millions of boulders from the areas of crystalline rocks in northern Wiscon-

sin, Michigan, and southern Canada, and deposited them over the surface of the land to the south.

These boulders represent the greatest variety in kind, color, and hardness. Often as many as ten or fifteen varieties of igneous rocks may be distinguished in a single small area. The colors are red, brown, and green, of many shades. The soundness of much of this stone attests its durability. Nothing but the most durable stone could withstand transportation by a glacier for 500 or more miles, without being crushed into sand and gravel or ground into clay. This is one of the reasons why sandstone and limestone fragments are seldom transported far from their place of origin.

The granite boulders frequently weigh several hundred pounds, and in many places they have been found weighing several tons. The boulders are generally of a size suited to easy handling, and have the advantage of being already quarried. The farmer looks upon these "hard heads," as they are called, as one of his worst enemies. He often works many days with a team to remove them from a small area, so numerous are they in some sections of the state. After they are picked up, they are generally either gathered in stone piles, built into fences, or used as foundation stone on the farm.

There are a number of uses to which glacial boulders are nicely adapted, viz.: building, foundations, and retaining walls. When the workmanship is good, there is nothing prettier, or more unique, than a building or retaining wall constructed from different colored boulders. The best illustration in this state of the use of glacial boulders in the walls of a building, is the depot of the C., M. & St. P. Ry. at Oconomowoc. This building is shown in Plate XVIII., Fig. 1. The building must be seen to be appreciated, because it is not possible to bring out the color in an ordinary photographic reproduction. The use of this supply of building stone will probably, in the future, be much more general than in the past. When people become better acquainted with the durability of this stone, and the beautiful effects which may be produced, by a careful arrangement of colors, it will be largely used in preference to the less

durable white and gray limestone or sandstone, which is often quarried in the same vicinity.

CONCLUSION.

The granite industry of Wisconsin is still in its infancy. Each year has been more or less of a struggle in competition with the granite from the eastern quarries. Many of our people are natives of the New England states, and they know no other granite except that from Vermont, Maine, New Hampshire, or Massachusetts. Without a reputation, Wisconsin granite has been obliged to enter the market and make one. This it has done, but only after much money has been spent in the pioneering work. Wisconsin granite now has a national reputation, and quarries which are opened in the future will find less opposition to the use of their product. The undeveloped granite resource of Wisconsin is simply enormous. There are hundreds of acres of land in the northern part of the state where excellent granite outcrops at the surface. There is a diversity in color and texture, sufficient to satisfy the tastes of almost any person. A comparison of the tests of Wisconsin granite, given in this report, with those of granite from other localities, as shown by the tables in Chap. VIII., indicates, that a person can make no mistake in purchasing Wisconsin granite.

No person ought to feel any timidity about purchasing a monument hewn out of Wisconsin granite. Neither ought one to think of using a foreign granite, when equally as good, if not better, stock can be purchased from quarries within our own state. We ought to take a pride in constructing monuments and buildings out of stone quarried in Wisconsin, whenever suitable material can be procured to equal advantage.

In past years granite operators have experienced difficulty in placing the stone from their quarries on the home market, as cheaply as their eastern competitors. Eastern granite companies have been able to lay down their stock in Milwaukee and Madison at a less price than the same kind of stone could be ob-

tained from quarries within our own state. Four reasons are apparent to account for this condition. First, the stone in the eastern states occurs, naturally, in some of the quarries, in dimensions more suitable for economical working. Second, more improved facilities for quarrying are used in the east. Third, the wages for laborers and skilled workmen are lower in the east than in the west. Fourth, transportation rates are cheaper. All of these circumstances have contributed their share in hampering the granite industry of Wisconsin. The eastern quarries have been opened for a great many years, and have reached a point where the stone can be utilized with greater economy than from the new quarries of the west. When a granite quarry is well developed, it is much easier to secure suitable dimensions than when the quarry is first opened.

Quarrying operations in this state are begun, as a rule, with limited capital, which excludes the use of improved machinery. It is next to useless for one to expect to successfully operate a granite quarry which is not provided with suitable machinery. A hand derrick will never compete with a derrick that is worked by steam. A drill cannot be operated by hand as successfully as by steam. A stone can be dressed much more cheaply by machinery than by hand.

But this is not all. It was for many years difficult to secure the services of skilled stone cutters, without paying a premium over the wages paid by eastern quarry operators. Today, although the wage difference is not so great, this same difficulty must be met by the quarry operator.

The transportation rates from the British Islands to the United States have been very low, much of the stone being brought over as ballast. The freight rates west have been much less than the rates east, which has very materially aided eastern operators in placing their product on the western market.

As the state is becoming better settled all of these causes for the slow development of our granite industry are passing away. It has been observed in the previous pages that the stone from many of the Wisconsin quarries can be quarried in any required

dimensions. The wages paid the workmen are reasonable, and compare favorably with the wages paid quarrymen in the eastern states. The machinery used is now the best on the market. New railroads and spurs have aided transportation. The western producer is constantly nearing the point where he can meet his eastern competitor on equal terms. Above all, people are coming to appreciate the true merit of Wisconsin granite, and to know that there is none better in the world.

II. THE METAMORPHIC ROCKS.

QUARTZITE.

The rocks treated under this special head are metamorphosed sedimentaries, and are in no way related to the igneous rocks discussed in the first part of the chapter. Unfortunately, quartzite is frequently spoken of as granite. But nothing could give one a more mistaken idea of the true character of the rock than to name it a granite. Its origin is essentially different from that of granite or rhyolite. Originally it was a sandstone, formed through aqueous deposition, which later became hardened and cemented through metamorphic agencies. We regret that there are still companies that place quartzite upon the market as granite.

Quartzite is quite widely distributed in isolated areas, throughout that portion of the state largely underlain by sedimentary rocks. It is all of pre-Cambrian age, and thought to be mainly Upper Huronian, although, in some instances, there is no reliable evidence on this point. Numerous outcrops of quartzite occur in Sauk county, some thirteen distinct areas having been mapped. Together they constitute what are known as the Baraboo Bluffs. Extensive outcrops are found in Barron county, near Rice Lake, in Jefferson county, near Waterloo, and in Dodge county, near Portland. The areas in Jefferson and Dodge counties are known as the Waterloo quartzite.

Other large mounds of quartzite occur in Juneau county, near Necedah, and in the central portion of Chippewa county in

T. 32, R. 7 W. Besides the above mentioned areas, quartzite outcrops at many places within the great northern crystalline area, but the outlines of these areas have not yet been determined.

Among the uses for which quartzite is quarried in Wisconsin are paving, macadam, monument bases, furnace lining, and sand paper. For rough work, where large dimensions are not desired and cutting and dressing are unnecessary, the quartzite may be used. It is one of the hardest and most durable stones, being composed almost entirely of quartz, sometimes stained red or brown, with a small percentage of iron oxide. The color ranges all the way from grayish white to dark reddish brown. It is one of the most refractory of stones and dresses with exceeding difficulty.

The quartzite of the more southern areas, the Baraboo Bluffs and Waterloo, has been quarried for a number of years. At each of these places there is an unlimited supply, easily accessible, and adjacent to the railroad.

On the Baraboo Bluffs quarrying has been conducted at two places, Devil's Lake and Ablemans. The former place is located on what is known as the south range, while the latter is on the north range. The Wisconsin Granite Co. operates at Ablemans, and the Western Granite Co. at Devil's Lake. These company names are both misleading, inasmuch as the stone being quarried is not granite, but quartzite.

The crushers are located near the foot of the bluffs, immediately adjacent to the railroad track. The stone does not require much handling, and at present is mainly obtained from large detached fragments which are thickly strewn over the hillsides. Across the valley, and a short distance south of the Wisconsin Granite Co.'s works, at Ablemans, the Illinois Iron and Steel Co. are quarrying the quartzite quite extensively, and using it for metallurgical purposes.

The quarry near Portland, in the Waterloo quartzite area, is owned by Ph. Fuchs, and has been operated for a number of years by the Berlin-Montello Granite Co. The quarry was opened in 1882, and has been operated more or less each year

since. Nine openings have been made at various places on the quartzite knolls, but the stone has been furnished mainly for street purposes,—macadam and paving blocks. It has also been used to a limited extent for monument bases, and, to some extent, the finer product of the crushed stone has been used in the construction of granolithic walks.

The value of the stone for macadam and paving blocks depends largely upon the way in which they are used. Crushed stone which is to be used for macadam should possess two distinct qualities. First, it should be durable, i. e., capable of resisting wear. Second, it should be of such composition that it will serve, in itself, as a binding material, whereby the road-bed will be so compacted at the surface that it will shed water. The quartzite possesses to an admirable degree the capacity to resist wear, but it is poorer in the binding quality. One should not infer from this that the stone is unsuitable for macadam. On the contrary, it is far superior to many of the softer rocks now used for this purpose, and can be so combined with other crushed stone, as to make an admirable road-bed.

For paving purposes the stone is very durable, but after a short time the blocks become very slippery, and for this reason they are less sought after than granite.

Except for local purposes, no attempt has ever been made to develop the remaining quartzite areas. The location of certain of the mounds is such as to suggest that in the future the stone may serve as a desirable source of material for road construction. Whether or not it will be thus utilized, remains to be seen.

CHAPTER III.

SANDSTONE.

One of the most widely distributed building stones, and one which furnishes perhaps the greatest variety in color and texture among the sedimentary rocks of Wisconsin is the sandstone of the Potsdam and St. Peters formations. A glance at the general map, Plate I., will give one a better idea of the general distribution of these formations than can be obtained from any verbal description. The Potsdam sandstone has a much larger surficial distribution than the St. Peters, and is of relatively greater importance as a source of building stone. Beginning in the northeast corner of the state at the Menominee river, the Potsdam formation swings in a broad belt around to the southwest, and then again northwest, as far as the St. Croix river. A second small area of sandstone of the same formation skirts the south shore of Lake Superior from the northwest corner of the state almost to the Montreal river, and forms the immediately underlying rock of the group of islands known as the Apostle Islands. This area, bordering on Lake Superior, is known as the Northern or Lake Superior sandstone, while the large belt swinging south of the central complex of igneous rocks is known as the Southern Potsdam sandstone. The outline of the Southern sandstone belt is very irregular, both at its northern and southern limits. The width of the belt varies from 6 to 80 or even 90 miles. The Lake Superior sandstone belt is much narrower, having an average width of about 6 or 8 miles. The sandstone is everywhere underlain by Pre-Cambrian crystalline rocks. The sandstone south of the southern

area is overlain by the Lower Magnesian limestone, beneath which it everywhere disappears. The irregularity in the boundary of the sandstone throughout the south central and western portions of the state, is due to the rivers and creeks which have often cut their channels through the overlying Lower Magnesian limestone, exposing the Potsdam sandstone along the bluffs on either side.

The St. Peters sandstone extends in a very narrow belt, often not more that a mile wide, from the northeastern part of the state, near Marinette, in a southwesterly direction, as far as the state line on the south, and the Mississippi river on the west. In the western part of the state the formation is exposed in irregular isolated areas, in Crawford, Vernon, Buffalo, Pierce, and St. Croix counties. On account of the river erosion, which has brought the sandstone to the surface in many of the valleys in the southern and western parts of the state, the surficial distribution, like that of the Potsdam, is very irregular. The sandstone outcrops more generally in the southern part of the state than elsewhere. It is everywhere underlain by the Lower Magnesian limestone and to the south and east passes underneath the Trenton limestone formation. The characteristics of the St. Peters formation, and the quality of the building stone which is quarried, will be considered in a later part of this chapter.

It is our purpose to treat the sandstone of Wisconsin in three distinct parts: (1) the Northern Potsdam, or Lake Superior; (2) the Southern Potsdam; and, (3) the St. Peters sandstone.

THE NORTHERN POTSDAM SANDSTONE.

The Potsdam sandstone of the Lake Superior region is ordinarily known as the Lake Superior Brownstone. It differs very decidedly from the sandstone of the Southern Potsdam and St. Peters formations, both in color and physical characteristics. A number of years ago the demand for brown sandstone was very great, and at that time some of the most extensive and well equipped quarries in the state were developed

in this region. These quarries are clustered either in the vicinity of Bayfield and Washburn, or scattered along the south shore of Lake Superior. A large portion of the region immediately underlain by this formation is unsettled, and the possibility for future development of the brownstone industry cannot be estimated.

The sandstone belt comprises a strip of land, adjacent to Lake Superior, about 6 or 8 miles wide, extending from the northwest corner of the state almost to the Montreal river on the east. At many points along the lake, between Superior and the eastern limit of the sandstone, the shore is skirted by bold sandstone cliffs, which are so situated that they afford excellent opportunities for quarrying. The Apostle Islands are mainly composed of brown sandstone, which in many places forms bold precipitous coast lines. Everywhere the sandstone is more or less concealed underneath a thin mantle of clay.

The Lake Superior sandstone region naturally divides itself into two areas, called respectively the Chequamegon and South Shore. The former is made to include all the region east of R. 7 W., while the latter includes the region west of R. 6 W. The South Shore interests are centered at Superior and Duluth, while those of the Chequamegon area are centered mainly at Ashland, Washburn, and Bayfield.

CHEQUAMEGON AREA.

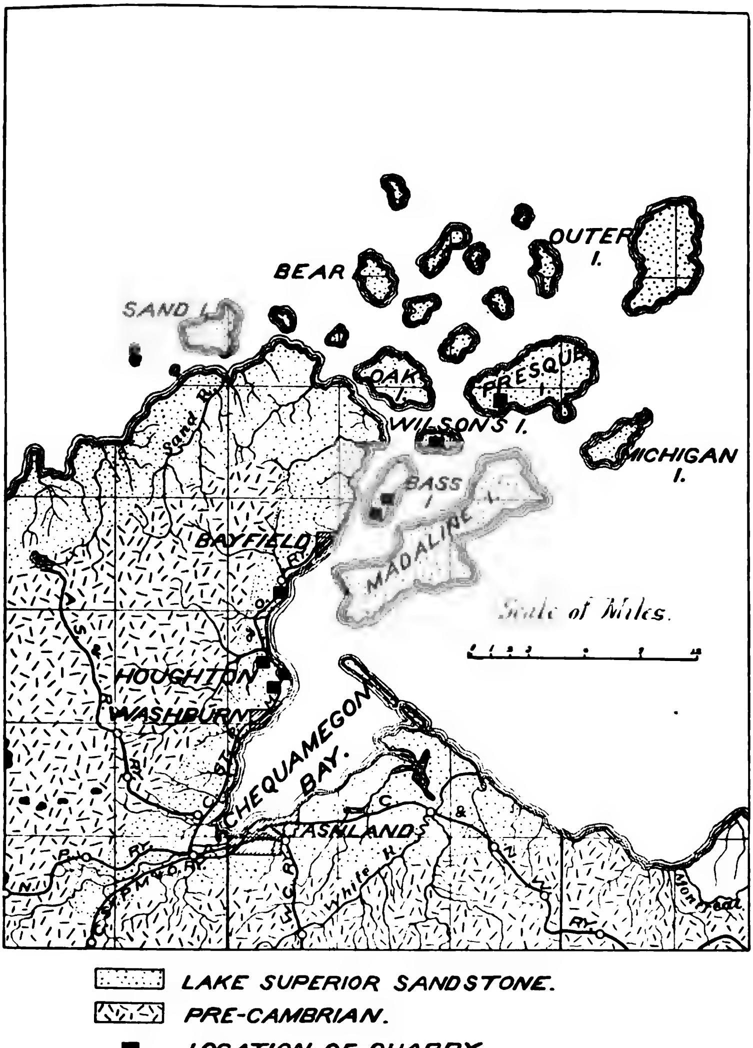
The approximate distribution and extent of the brown sandstone of the Chequamegon area is shown on the sketch map, Plate XXII., after Prof. T. C. Chamberlin. The distribution indicated comprises not only the areas where sandstone actually outcrops, but also the area covered with surface soil, which is supposed to be underlain by sandstone. From Ashland to Bayfield, the sandstone outcrops in many places along the shore, often in vertical or overhanging cliffs of considerable height. The Apostle Islands, which are also included in this area, are largely composed of sandstone, which is best exposed about their margins. Only a few of the many favorable localities for quarrying, either on the islands or mainland, have thus far been exploited.

The first quarry in this area was opened in 1868 on Bass Island, by the Bass Island Brownstone Co. The first stone quarried was furnished to build the Milwaukee Court House, in 1870, and people expressed many grave fears respecting the advisability of using a new and untried stone in such an important structure. The difficulties which the early operators experienced in placing their product on the market is well depicted in the newspaper comments and the reports of committees and experts, on the suitability of the Lake Superior brownstone, for use in this building. In a report to the Board of Aldermen, published in the *Evening Wisconsin,* March 16, 1869, the fitness of the stone was questioned by Messrs. Gindele, Chesbrough, and Bauer, of Chicago; by Cols. Wheeler and Farquhar of the U. S. Engineers office of Milwaukee; and by J. L. Whittemore, Engineer of the C., M. & St. P. Ry. After careful examination it was pronounced in all respects suitable, by Prof. I. A. Lapham, LL. D., Peter White, Esq., of Marquette, Michigan, Prof. James Hall, of Albany, New York, Wm. R. Sill, late Chief Engineer of the La Crosse & Milwaukee R. R., and Mr. N. Merrill, a well known stone cutter. It was in the face of a very considerable opposition, mainly by engineers, who favored a conservative policy, that the Court House was finally built of brownstone from the Bass Island quarries. The building has not crumbled or fallen in a few years, as was predicted, but stands today almost as fresh as if it were built but yesterday.

The credit for first developing the brownstone industry probably belongs to a prospecting party, of which Mr. Almson Sweet of Milwaukee was a member, and in which Mr. D. L. Wells of Milwaukee was largely interested. Since the opening of the first quarry on Bass Island seven other important quarries have been developed in this area.

Quarry Observations.

The sandstone occurs in heavy beds, often 12 or 15 feet in thickness. Thin layers of clay or shaly material, from 1 to 5 feet in thickness, are occasionally interbedded with the sandstone. It often happens that stratification planes cannot be ob-



CHEQUAMEGON AREA.

served except where cross bedding occurs. The stone possesses a capacity to split readily, parallel to the bed, at almost any depth.

Two major sets of jointing planes, striking about north and south, and east and west, occur in most of the quarries, although in a few the strike is northwest and southeast. These joints are approximately vertical, and generally smooth sided. Two sets of joints, dipping generally at an angle of about 45°, occur at irregular intervals in many of the qu rries. Fortunately they are not abundant. The regular joints are too far apart to be of assistance in quarrying and are therefore seldom made use of. Blocks of any desired size can be obtained at all the quarries, where the facilities for handling are adequate.

The amount of soil stripping depends upon the location of the quarry, and varies from nothing, in some quarries, to 10 or 12 feet in others. If the capping of soil is light, the sandstone, to a depth of 10 or 12 feet below the surface, is generally much broken up. Stone taken from this part of a quarry is used mainly for pier and breakwater purposes, and seldom more than pays for its removal.

Where the surface of the sandstone has been exposed to the weather for many centuries, it has a light grayish or yellowish brown color, which extends to a very shallow depth below the surface. Lichens grow in many places on the natural exposures, giving some evidence of durability. The stone obtained from the several quarries of this area is very similar, differing mainly in the shade of color and fineness of grain.

The shade of color varies not only between different quarries, but also between different beds in the same quarry. The sandstone from certain quarries has a light reddish brown color, while that from others is very dark, having almost a bluish tone. Besides the many shades of brown and red, white streaks and spots occur in portions of certain quarries, giving the rock a variegated color. The different shades of brown are nicely shown in the accompanying plate. (See Pl. XXIII. Also Pl. XXXIV.) Between the dark and light shades, there are many intermediate tints, which give va-

riety to the color effects of the stone. In any particular opening the differences in color are mainly between the different beds. The color of the stone in the individual beds of a quarry, is generally uniform throughout any single opening. When observed at a short distance, the different shades of brown in many of the beds is scarcely noticeable. The color is in all respects permanent, decoloration resulting only after thousands of years of exposure, and then, as shown by the rock in the natural outcrops, it only affects the surface.

The white spots and streaks mentioned above are only objectionable when stone of absolutely uniform color is desired, and are in no way related to the strength or durability of the rock. The white spots and streaks do not occur throughout any considerable portion of the quarries, although none of the quarries in this area are entirely free from them.

The sandstone is composed mainly of medium sized grains of quartz, with which occasional feldspar grains are mingled. The grains vary in size in different samples, but are fairly represented in Plates LXIV. and LXV. The grains are subangular in shape, and more or less cemented together by secondary quartz. Iron oxide, in the form of dirty, reddish brown hematite, is present in all the samples, coating the grains and giving coloring to the rock, but not serving as an important cement, as some have suggested. Besides these abundant constituents, the sandstone also contains occasional grains of chert, and small amounts of argillaceous material. A close examination shows that the sandstone is sufficiently well cemented for all practical purposes, and that the mineral constituents are such as will decompose only with great difficulty.

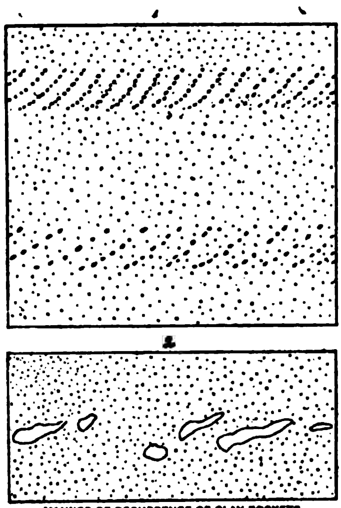
Certain portions of individual beds, in all the quarries of this area, are more or less injured by what are commonly known as clay pockets. Stone which is affected by clay pockets is very appropriately spoken of by the quarrymen as having the "liver complaint." The clay pockets are small, oval, or irregular nodules of soft clay, which readily disintegrate and fall away from the stone, after it is exposed for a short time to the weather. The result is a shallow depression or cavity in the

1.

2.

LAKE SUPERIOR BROWN SANDSTONE. FROM CHEQUAMEGON AREA.

face of the rock. The clay pockets range all the way from those the size of a pea, to those which are 2 ft. long by 6 in. thick. (See Fig. 3.)



MANNER OF OCCURRENCE OF CLAY POCKETS.

FIG. 3.

It cannot be denied that clay pockets are an objectionable feature of the sandstone. Where they are very large or numerous, the strength of the stone may be somewhat lessened by their presence; but if small and of only occasional occurrence the strength of the stone will be little, if any, affected. The most undesirable feature of the stone containing clay pockets is the appearance of the pitted surface. If the pockets are small and do not appear on the exterior of the wall, they can hardly be considered injurious. Stone which is graded No. 1 contains no clay pockets of injurious size, and by careful selection and cutting, much of the stone, which is condemned on account of these imperfections, could be used for the same purposes that the No. 1 stock is now used for. A large percentage of stone in most of the quarries is free from clay pockets, but the relative amount in some quarries is much greater than in others. Naturally, these conditions influence to some extent the standard by which the stone is graded.

Certain beds in the quarries also contain layers in which small pebbles are embedded. Upon dressing the surface, these pebbles occasionally fall out, leaving cavities similar to those formed by the weathering of the clay pockets. The pebbles are uniformly small, and generally so firmly cemented in the matrix, that they dress down with the sandstone itself.

In places, the iron oxide, which gives coloring to the rock, has been so concentrated along certain of the sedimentary planes that the rock has a streaked appearance. The stone in certain parts of the quarries is cross bedded, but, in general, the beds have such a uniform texture that the stratification planes cannot be detected, except on the weathered surface.

These imperfections do not occur in the No. 1 stone, but are characteristic of the poorest stone in all the quarries. In some quarries they are more abundant than in others, but the only way that they injure the quarry is by limiting the amount of No. 1 stone that can be obtained. If a quarry contains a large amount of inferior stone, the tendency is to lower the grade, which results in the purchaser actually buying stone of mixed grade for No. 1. The quarryman is responsible for this condition, and not the quarry. It is possible to obtain clear stock, uniform in color, free from clay pockets, pebbles, or white spots, in practically unlimited amounts, from any of the quarries of this area.

Laboratory Examination.

Microscopical Examination.—The microscopical examination shows a difference in the size of the individual grains, composing the stone from the different quarries, and a slight difference in mineralogical composition. The grains which make up the rock are not so well rounded as would ordinarily be supposed, but are largely subangular in outline. They consist mainly of quartz and an occasional grain of feldspar and chert. Iron oxide is quite uniformly present as a thin coating about the grains, but is more abundant in some sections than in others. Argillaceous material is disseminated in small amounts through the interstices, but is not sufficiently abundant to be harmful to the

strength of the rock. The quartz grains are cemented mainly by silica. The iron oxide is primarily a coloring agent, although it may probably also serve as a subordinate cementing material. (See Pl. LXV.)

Chemical Analysis.—Chemical analysis No. 1, made upon brownstone from Bass Island, is taken from the Geology of Wisconsin, Vol. I., p. 304. No. 2 was made for this report by Prof. W. W. Daniells, from a sample of brownstone from Babcock & Smith's quarry, Houghton.

	No. 1.	No. 2.
$Si\ O_2$	87.02	86.57
$Fe_2\ O_3$	3.91	1.55
$Ca\ O$	.11	trace
$Mg\ O$	.06	of MnO
$Al_2\ O_3$	7.17	8.43
$K_2\ O$	1.43	2.36
$Na_2\ O$	.22	0.67
	99.92	99.58

These analyses show a high percentage of silica and a comparatively low percentage of aluminum, both of which are favorable to the durability of the stone. The presence of a very considerable amount of potassium indicates that feldspar is a somewhat abundant constituent of the rock.

Hardness.—The brown sandstone from this area is harder than many sandstones of this character, as shown by a comparison with the red sandstone of Michigan. The Wisconsin brownstone saws four inches an hour, while that from Portage Entry runs as high as 28 inches per hour. This difference is so great that there is no question as to which of the two stones is the harder.

Physical Tests.—The average crushing strength of the brownstone is above that required for ordinary building purposes. Reference to Chapter VIII., Table II., shows that the brownstone of this area has an average compressive strength of over 4,500 lbs. per sq. inch on 2 inch cubes. This is 200 lbs. above the average crushing strength of 17 cubes of Bedford

oolitic limestone, as published in the report of the State Geologist of Indiana, for 1896.[1]

The transverse tests (See Chapter VIII., Table III.) show that the sandstone is capable of carrying only an ordinary load when suspended at the ends. The modulus of rupture, as determined in the laboratory of the University of Wisconsin, ranged from 464.2 lbs. to 574.6 lbs. per sq. in. The average of five determinations was 543.4 lbs. per sq. in. It is now customary to arch the windows and doors, instead of using single blocks for window or door caps. Used in this manner, the sandstone is sufficiently strong to support any load that may be required of it.

The average specific gravity of ten samples, given in Chapter VIII., Table V., is 2.637. The porosity, or percentage of actual pore space, recorded in the same table, is higher than most of the other rocks from Wisconsin quarries, and is apparently higher than sandstone from other states. But it must be remembered that in no other state report on building stones has an attempt been made to compute the actual percentage of pore space. That which is given in other reports is the percentage of the weight of water absorbed to the weight of the dry rock. This has also been computed for the Wisconsin stone. The results, called ratio of absorption in distinction from porosity, are given in the next column. The average porosity of the sandstone of this area is 20.19 per cent., while the ratio of absorption is less than one-half of this amount, or 9.59 per cent. Considering the medium grained character of the rock, and the large size of the pores, the possibility of danger from frost is very little. Sandstone, having a texture similar to that from this area, gives off any water which it may have absorbed, with such rapidity, that it is out of danger before the temperature can drop sufficiently to freeze the interstitial water.

Ten samples from these same quarries were subjected to al-

[1] The Bedford Limestone, by T. C. Hopkins and C. E. Siebenthal: 21st Ann. Rept. of the Dept. of Geol. & Natl. Resources of Indiana, 1896, p. 317.

ternate freezing and thawing, after the method explained on pp. 71 and 72.

The results are given in Chapter VIII., Tables VI. and VII. The average loss in weight after 35 days' exposure, on cubes weighing from 265.8 to 412 grams, amounted to only .395 of a gram, or less than one-sixth of one per cent. The average loss in strength, as shown in table VII., amounted to a little over 800 lbs. per sq. in., which is a loss of about 17 per cent.

Two inch cubes of sandstone from these quarries were placed in a muffle furnace, and gradually heated to a temperature of 1,500° F. When cooled, after being heated to a temperature of 1,000° F., the sandstone was apparently but little injured. At a temperature of from 1,200° to 1,500° F. the different samples were not cracked and gave no other external evidence of weakness. When tested, however, after being allowed to cool, the strength was found to be largely gone. The samples could be powdered between the fingers. (See Plates LVI., and LVII.) It appears that in the case of sandstone the injury is occasioned mainly through a loosening of the individual particles composing the rock, rather than by fracturing or scaling off, as in the case of stone, in which the grains interlock. The fact that the sandstone samples were destroyed at the high temperature of 1,200° to 1,500° F. simply indicates, as in the case of the granites and limestones, with which they were tested, that no stone, however well compacted, or fine grained, can remain uninjured when heated to this extreme temperature. That the sandstone was apparently little injured at temperatures of less than 1,000° F. is abundant evidence that it would be little injured by the burning of the interior of any ordinary building. It is to the advantage of the sandstone that it does not flake or crack, when subjected to this extreme heat, although this very characteristic might deceive one in estimating the injury done the stone by a conflagration.

The above laboratory tests are sufficient to indicate that the Chequamegon brownstone is adapted to a great many uses. Es-

pecially is the stone well suited to all kinds of building construction. It is sufficiently strong to withstand the weight of the most massive structures now built, and its durability, when properly laid and dressed, is unsurpassed by any other sandstone.

The Output.

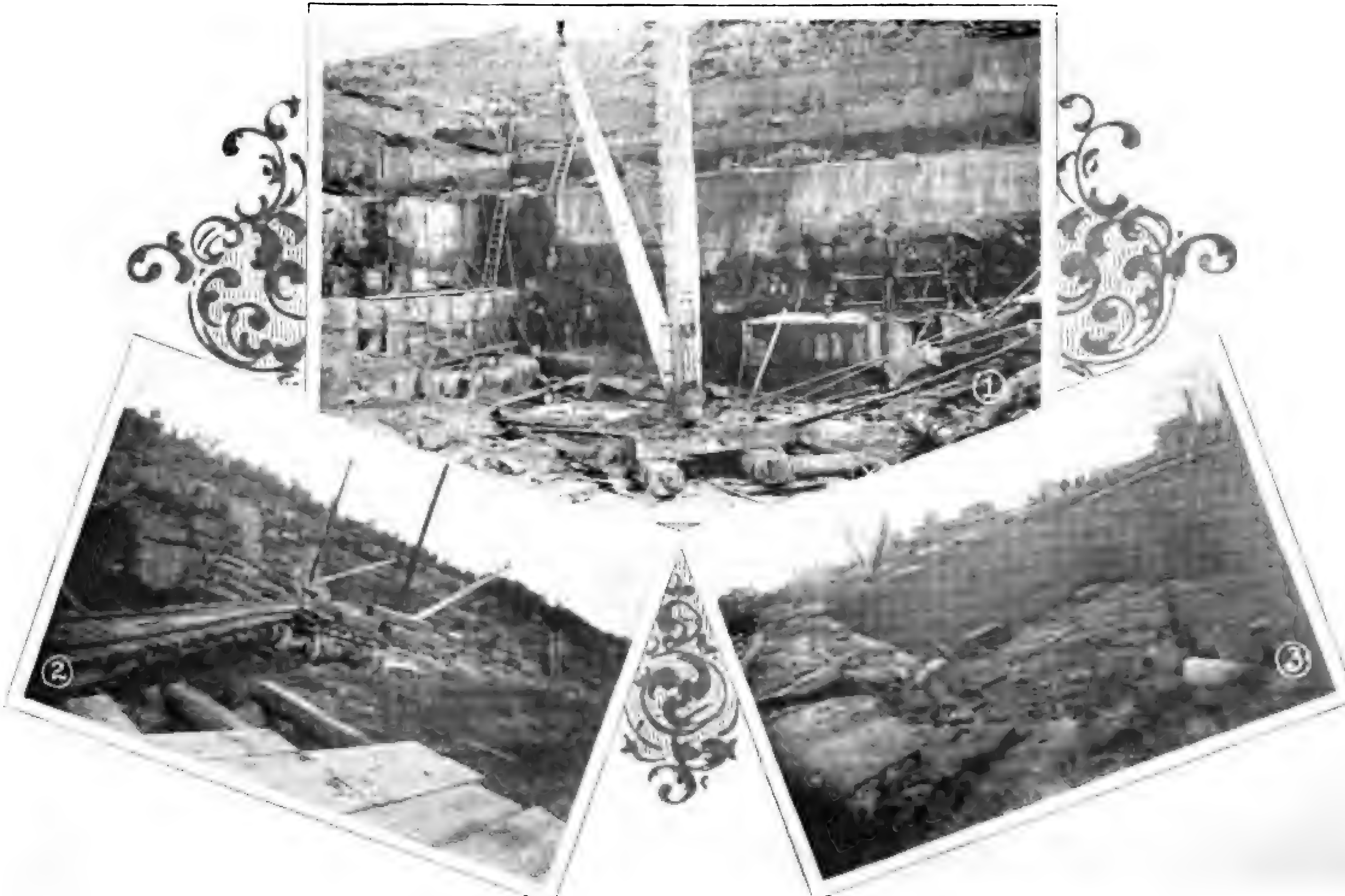
The output from these quarries is generally graded and sold, on board the cars, in rough scabbled dimension blocks. None of the quarry operators, to my knowledge, dress any of the stone at the quarry. It is generally graded into Nos. 1, 2 and, occasionally, 3 mill blocks; Nos. 1 and 2 ton stone; and rubble. The stripping is sometimes sold under the name of rip-rap, but this stone is worthless for most purposes, with the possible exception of filling for breakwater.

The brownstone in these quarries cannot be successfully worked by blasting, on account of the readiness with which it is shattered and broken. In some instances quarrymen have attempted to work their quarry by blasting, but more stone has been destroyed and injured, through this crude method, than would furnish profit to a large concern. The only successful method of exploiting this stone is by the use of channeling machines and wedging. The stone should be cut by channelers, in two directions, and then wedged off along the bedding plane to the desired thickness. The channel cuts are ordinarily about eight or ten feet deep, but it is customary in removing the blocks to make them two or three feet in thickness across the bed. A number of the quarries are equipped with sawing machines, by which the stone can be cut into any desired dimensions. Where a quarry is provided with facilities for sawing, the stone can be much more readily and satisfactorily graded than otherwise.

Description of Individual Quarries.

BASS ISLAND BROWNSTONE CO.

Historical.—The Bass Island Brownstone Quarry is located on Sec. 4, T. 50 N., R. 3 E., at the south end of Bass Island, one



LAKE SUPERIOR SANDSTONE QUARRIES.

1. Iron River Quarry. 2. Pike's Quarry. 3. Babcock and Smith's New Quarry.

of the Apostle Islands, at the head of Chequamegon Bay. This place was selected in 1868, by Capt. Sweet and other prospectors, who had spent some fifteen months prospecting along the shore of the bay and lake. After the land had been purchased, the necessary buildings were erected, docks were built, and machinery placed in preparation for the development of the first brownstone quarry of northern Wisconsin.

The stone for the first building, constructed out of Lake Superior brownstone, in Wisconsin, was taken from this quarry. As previously stated, that building was the Milwaukee Court House, the erection of which was begun in 1869. The difficulties, which the company experienced in placing the stone upon the market, have been rehearsed at the beginning of this chapter. In order to meet the objections of parties, touching the safety of the sandstone, as a building material for important structures, samples of the brownstone were sent to the Smithsonian Institution, Washington, D. C., and were there analyzed and thoroughly tested. The report of the Smithsonian Institution was entirely favorable to the brown sandstone, as a building material, and assisted very materially in the development of the industry at that place.

In 1871 Chicago capitalists became interested in the Bass Island Quarry, and for some years the output was principally utilized in that city; but during the rebuilding of Chicago, after the memorable fire of 1871, the management became seriously involved. Legal difficulties arose affecting portions of the title to the quarry realty, machinery, and marine adjuncts, which led for a number of years to comparative inaction. About 1879, the quarry was leased by a new firm, and the output for a number of years was very fair. This firm, however, operated large limestone quarries, and hence had no special interest in exploiting sandstone exclusively. From 1885 to 1889 local circumstances connected with the brownstone interests in the Lake Superior region created some business uncertainty and disquiet, and the output of this and other quarries, of younger growth, was materially reduced.

In 1891, the quarry was leased to the Superior Brownstone

Co., which gave its name to the output of the quarry. Until the panic in May, 1893, this company conducted a successful and growing business, building up a strong and healthful reputation. The alarming depression, incident to that time, induced the entire stone interest to curtail operations, which policy has continued up to the present time. During the last few years no work has been done in this quarry, except in stripping and utilizing the surface for rubble purposes. This, however, has greatly improved the condition of the quarry.

During the time that the quarry was operated by the Bass Island Co. the output was transported exclusively by water, railroads being unknown at that time in this section of the country. The company owned two vessels by which the transportation was carried on.

The quarry and equipment, including 85 acres of land, is now owned by Mr. Geo. P. Lee, of Chicago.

Quarry Observations.—The quarry consists of one large irregular opening about 400 feet long, 300 feet wide and 40 feet deep. The top of the quarry consists of from 3 to 4 feet of clay soil, which constitutes the maximum dead stripping. The 15 feet immediately underneath this is rubble. Up to the present time the sale of this rubble for pier, breakwater, and other similar purposes, has paid for its removal. The bed of rubble is followed by 2 feet of soft, worthless, argillaceous material. Below this is a bed of from 7 to 7½ feet of mainly No. 2 stone. This bed contains very few clay pockets, and much of the stone might be sorted, so as to be salable as No. 1. Immediately beneath this is a bed of from 8 to 10 feet of No. 1 stone, from which blocks of any dimension may be obtained. The upper part of the bed, in some parts of the quarry, is cross bedded, and undesirable for building purposes. This is the lowest bed in the quarry, but the sandstone has been tested by means of drill holes to a depth of 20 feet below this floor, giving evidence that to this depth the stone is of a somewhat inferior quality. Below this, the drill passed to some depth through clay layers. The clay pockets in the bed of No. 2 stone are generally small, but in places they are quite abundant, giving the rock a somewhat vesicular appearance.

The bed of No. 1 stone is exposed for about 250 feet, and is generally uniform throughout. It contains an occasional clay pocket, which may be easily avoided in cutting and dressing.

In different parts of the quarry one occasionally finds a few very small pebbles embedded in the matrix of the sandstone. The pebbles are not sufficiently large to be deleterious to the stone, and are of such infrequent occurrence as to be scarcely worthy of serious attention.

It is somewhat difficult by an examination of the quarry face, on account of its long exposure to the atmosphere, to determine how much of the stone is spotted or variegated with white, but it is thought from the general appearance that the variegated stone is not abundant.

General Considerations.—The stone has been used largely for buildings, basements, piers, and foundations. Dimensions of any size under 175 cubic feet can be ordinarily quarried, but for transportation purposes the stone is usually cut into blocks about 8 feet, by 4 feet, by 2 feet.

The markets for the stone have been mainly Wisconsin, Minnesota, Illinois, Indiana, Iowa, Nebraska, Dakota, and Michigan. A few of the numerous buildings which have been constructed out of this stone will be found among the brownstone buildings listed at the close of this chapter. Attention may well be called to the fact that the stone in all of these buildings has thus far withstood the elements without any unwarranted decay. St. Paul's church in Milwaukee was built out of brownstone from this quarry, in 1883. The stone has a rock face finish, with carved door frontals and tower carvings. The fine carved edges remain sharp and distinct, and unless the structure be subjected to unnatural treatment it is apparently good for generations to come. This might be said of many other structures which have been built out of the brown sandstone from this, as well as other quarries.

Samples of stone from this quarry were thoroughly tested in the preparation of this report. The results are given in the tables, Chapter VIII. The best stone was found to be equal in strength and durability, to most others of this kind, and in all respects suitable for building purposes.

Statistical Data.

Facilities at hand for quarrying: 2 engines, 3 channelers, 3 steam derricks, 1 hand derrick.

Cost of cutting and dressing stone per square foot: Sawn, $.20.

Cost of transportation: $.10 to $.12½ per 100 lbs. by rail; $1.75 to $2.25 per ton by water.

Average value of each grade per cubic foot: No. 1, $ 50; No. 2, $.40.

BRECKENRIDGE QUARRY.

Historical.—About a quarter of a mile north of the Bass Island Brownstone Co.'s quarry is a small opening known as the Breckenridge quarry. It appears that Col. Breckenridge, of Kentucky, was one of the joint owners of a tract of land embracing most of Bass Island. The Bass Island Brownstone Co. bought out a number of the interested parties, and then leased the south end of the island and opened the quarry which has just been described. Through legal proceedings, the whole property was afterwards divided into individual interests, and allotted to the respective partners. Col. Breckenridge's allotment was next north of the Bass Island quarry property, and showed signs of brownstone. In 1892 it was leased for the purpose of developing a quarry. A considerable amount of stone was blown out with powder, but on account of lack of means to supply power and machinery, the work was abandoned after two or three shipments of the broken stone.

Quarry Observations.—The soil has been removed along the shore for a distance of 80 or 100 feet north of the quarry, exposing a very good ledge of stone. The face of the quarry is about 12 feet deep, and extends about 60 feet north and south. The stripping above the face is about 6 or 8 feet thick, but this will probably increase somewhat as the quarry is worked back.

The quarry face is composed of two beds, both of which are comparatively free from white spots. The upper bed is about 7 feet thick, and the lower measures from 4 to 6 feet. A few small clay pockets were observed in both ledges. They occur in bands running through the center of the ledges, injuring the stone less than if they were scattered promiscuously through

LAKE SUPERIOR SANDSTONE.

Court House, Milwaukee, Wis.

the beds. Very few pebbles were observed in the stone. The color is very uniform. The joints strike east and west, and north and south, as in the previously described quarry.

The indications are very favorable at this locality, the stone is easily accessible, and the exposed beds are largely No. 1 stone.

ASHLAND BROWNSTONE COMPANY.

The quarry of the Ashland Brownstone Co. is located on the south shore of "Presque Isle" island, one of the Apostle Islands, about 8 or 10 miles northeast of Bass Island. This island is one of the largest of the group and contains an abundance of excellent building stone. The quarry on this island was opened in 1889, and has been operated continuously each year, until operations were suspended in 1897. The quarry is now leased by a Michigan company, which has been operating for some years in the Portage Entry sandstone.

Quarry Observations.—The company controls about 91 acres of land surrounding the two openings, from which a major part of the brownstone has been quarried. The first opening, which is adjacent to the shore, has a very irregular outline. The main face of this opening is about 45 feet deep, and consists of 12 benches. Nearer the lake the quarry has been developed about 28 feet deeper, making in all 19 benches, with a total thickness of about 73 feet.

The upper portion of the quarry, comprising 6 benches, is considerably mottled and streaked with white. The lowest 12 feet include the hardest and most uniformly textured and colored stone in the quarry. The intervening beds are mottled in certain parts with white streaks and spots.

The upper benches contain numerous vesicles caused by the weathering out of small clay pockets. The lower 12 feet contain only occasional large pockets, generally occurring near the center of the bed. They are few in number, and do not interfere with the possibility of obtaining excellent No. 1 dimension stone. No. 1 stone can be obtained from nearly all the benches, but the different qualities of stone obtainable from different parts of the same bench, shows the necessity for carefully grad-

ing the output. One cannot point out any individual bed that is composed entirely of No. 1 stone. Certain parts of the benches are No. 1 stone, while other parts grade No. 2 or No. 3. The stripping of soil is very light, consisting at the most of only 2 or 3 feet.

The jointing and diagonal cracking are essentially the same as observed in the previously described quarries. Interbedded shaly layers were observed in one or two places, which, when followed for some distance, often "pinched out," being replaced by good stone.

The second opening is much smaller than the first, and is located on the side of the bluff above the first opening. The covering of soil is light, being not over 2 or 3 feet thick. This opening is about 255 ft. long by 105 ft. wide, and somewhat irregular in shape. The excavation comprises four benches in the deepest part, and two at either end. The stone from the upper bench is mainly rubble, while that of the three lower benches is largely No. 1. These benches are composed of remarkably clear, uniform stone, the best observed in either opening. The stone from these benches is remarkably free from clay pockets, and exhibits but few white streaks or spots.

General Considerations.—One of the commendable features of the quarry is its freedom from accumulations of rubble and stripping, which in many quarries interferes with easy working. The company is well equipped with modern machinery for quarrying, and is prepared to furnish stone for all purposes for which brownstone is used, including basements, piers, breakwater, and building. The markets are the same as those of the other quarries. The important buildings which have been constructed out of stone from this quarry may be ascertained by referring to the list of brownstone structures appended to this chapter.

The stone from this quarry was carefully tested, in the laboratory of the University of Wisconsin, in preparation for this report. The results of these various tests were eminently satisfactory, as may be seen by referring to the tables in Chapter VIII. It is scarcely necessary to repeat that the strength

of the stone is sufficient for all constructional purposes, and that it is probably not surpassed in durability by any brownstone used in this or neighboring states.

Statistical Data.

Amount of capital invested: $110,000.00.

Facilities at hand for quarrying: 3 75-hp. engines, 4 channelers, 5 steam derricks, 2 steam drills.

Average number of employees: 75 when running.

Wages paid different classes of employees: $1.50 to $3.50.

Cost of cutting and dressing stone per cubic foot: Sawn, $.25.

Cost of transportation: By rail, Chicago, $.10 per hundred; by water, Chicago, $2.00 per ton.

Average value of each grade per cubic foot: No. 1, $.50; No. 2, $.40; No. 3, $.30; ton, $2.50.

Shipment for the past five years:

1892	200,000 feet.
1893	175,000 feet.
1894	230,000 feet.
1895	285,000 feet.
1896	240,000 feet.

EXCELSIOR BROWNSTONE CO.

Historical.—The Excelsior Brownstone quarry is located on the southeast ¼ of Sec. 13, T. 51, R. 3 W., on Wilson Island, one of the group of Apostle Islands, between Bass Island and Presque Isle. The quarry was first owned and operated by Frederick Prentice, of the Prentice Brownstone Co., who purchased the land some time in 1857. In August of 1890, E. E. Davis, of Ashland, began the work of prospecting for the location of the quarry, and on the 2nd of May, 1891, the quarry was set in operation. The first cargo, consisting of 7,000 cu. ft., left for Buffalo, N. Y., on the 17th of June of the same year. In 1892, Mr. Prentice formed a stock company under the name of the Excelsior Brownstone Co., which has since owned and operated the quarry. Owing to financial difficulties, the quarry was not operated in 1897–98. Up to 1897, the average annual output was about 220,000 cu. ft., with the exception of 1896, when it fell to 100,000 cu. ft.

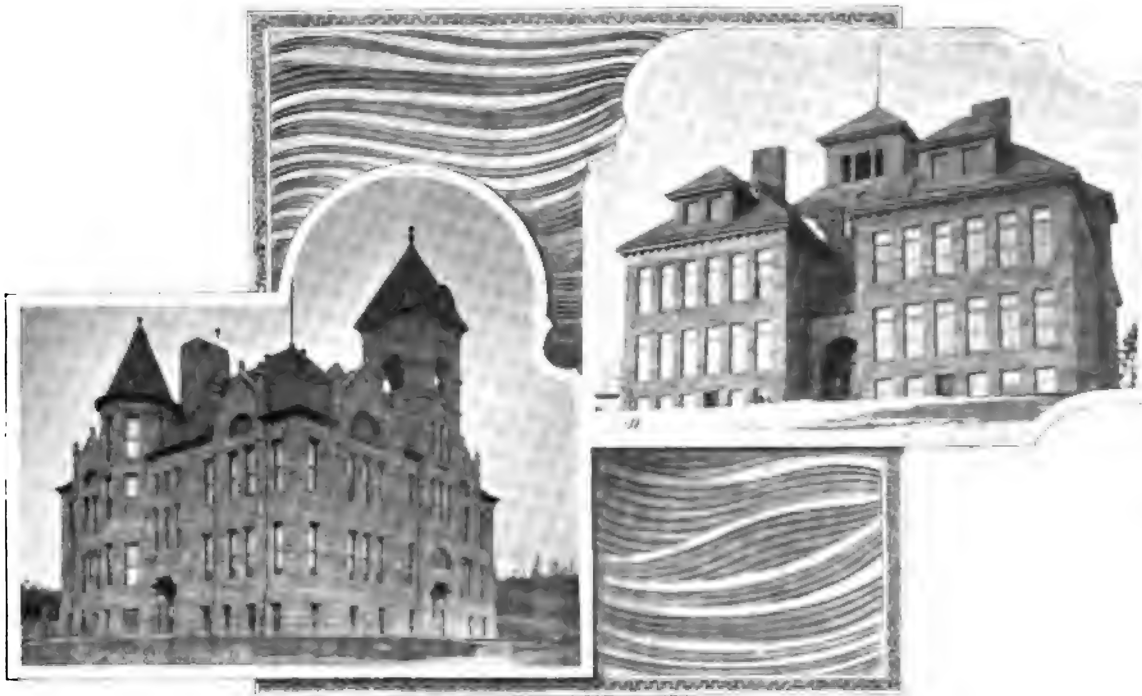
Quarry Observations.—The quarry on this island is located immediately adjacent to the shore, and consists of two openings. The sandstone outcrops along the shore, on either side of the quarry, exposing several beds having a thickness of 10 ft. or more. The opening farthest south is irregular in shape, having a face 180 feet long with a maximum thickness of about 20 ft. This is the smaller opening, and consists of four benches, the upper one of which is 4 to 8 ft. deep, while the other three are each 4 ft. deep. The stripping is very light, being not over 4 ft. thick, with the probability that it will not increase for a considerable distance back from the face. The jointing and irregular cracking of the face are essentially the same as that observed in the quarries on the neighboring islands.

The color of the sandstone is a shade or two lighter brown than that obtained from the other quarries of this area. Occasional light colored spots occur on the face of the quarry, indicating that the stone is mottled, in places, with white. That these are not abundant is shown by the large blocks, free from white spots, which have been quarried and left near the opening.

The most unfortunate feature of these beds is the occurrence of numerous small clay pockets. There is essentially no difference between the different benches in this respect. None of the exposed beds of this quarry can be classed entirely as No. 1, although it is possible here, as elsewhere, to obtain by careful selection, a limited amount of No. 1 stone. Pebbles are of infrequent occurrence, and occur mainly along the natural beds.

The second opening, which is a few rods north of the first one, is much the larger of the two, but the character of the stone in the different benches does not differ materially from those of the first opening. Operations have extended to a depth of about 32 feet, but the character of the stone in the lower benches is not materially different from that which is obtained from those higher up.

General Considerations.—The amount of stone which is accessible in this quarry is unlimited, as it is at the other brownstone quarries described in this report. The company is well equipped with machinery for quarrying, and each of the open-



LAKE SUPERIOR SANDSTONE.

1. High School, Bayfield, Wis.

2. High School, Washburn, Wis.

ings is provided with a good pier, built of logs and stone. About $150,000.00 have been invested in the development of this quarry. The different states and principal cities in which the stone has been used are given in connection with the list of brownstone buildings, at the end of this chapter.

Statistical Data.

Facilities for quarrying: 1 25-H. P. engine, 3 channelers, 4 steam derricks, tug, and scow.

Average number of employees: None at present.

Average value of each grade per cubic foot: No. 1, $.50, No. 2, $.30.

THE WASHBURN STONE CO.

The Washburn Stone Co. is located about 15 miles north of Ashland, at Houghton, between the cities of Washburn and Bayfield. The quarry was opened in the spring of 1885 by Babcock & Smith, who are the present owners. The quarry has been operated from April 1st to November 1st of each year, since it was opened.

Quarry Observations.—The company controls 72 acres of land, on which two openings have been made. The larger one is 375 ft. long, 150 ft. wide at the surface, and 65 to 70 ft. deep. At the bottom of the quarry, the lateral dimensions are about 69 ft. by 311 ft. This opening was worked continuously for 11 years, furnishing an enormous amount of stone for a variety of purposes. It was abandoned on account of the flooded condition of the quarry, which required the running of a pump night and day, to keep it in condition for working. The operations were also hampered by the occurrence of a bed, containing a great many pebbles. The smaller opening, which is the one now being operated, is 100 ft. long and 75 ft. wide, with an average depth of 17 ft. (See Plate XXIV., Fig. 3.)

The color of the stone from this quarry is ordinarily brown, or reddish brown, although that which is quarried from certain beds has a bluish tone. The stone taken from the upper 17 ft. of the quarry is mainly stripping and ton stone. Very little No. 1 block has been quarried at this depth. The beds are

slightly mottled with white spots and streaks, which, as a rule, are not of sufficient size to lessen materially the value of the stone.

Jointing and irregular cracking occur in this quarry, as noted in connection with the previously described quarries. The stone is remarkably free from pebbles and clay pockets. The stripping of broken stone is heavy, but pays for itself, through a contract which the firm has to furnish stone for a large number of bridge abutments and piers, for the Chicago, St. Paul, Minneapolis & Omaha railroad.

General Considerations.—The stone has been used quite extensively in buildings throughout the states of Wisconsin, Minnesota, Illinois, and Iowa. A number of the more important buildings, constructed out of the stone from this quarry, will be found in the list given at the close of this chapter. Besides being used in buildings, the stone is used quite extensively in the construction of bridge abutments and culverts. Some years ago Babcock & Smith induced the C., St. P., M. & O. R. R. to test the stone from their quarry in one of the bridges along their line. The stone was quarried in December and placed in the stone work of the bridge without being seasoned. The stone was placed in the bridge under the most unfavorable conditions, yet the solidity of the masonry has not been in the least affected thereby. The railroad company considers this bridge one of the best and most durable on their line. The masonry used in the railroad company's bridges and culverts is now almost exclusively constructed out of this stone.

The strength and durability of the stone, as tested in the laboratory of the University of Wisconsin, in preparation for this report, will be found by referring to the tables in Chapter VIII. These tests show that the stone is in all respects suitable for the purposes for which the quarry is prepared to furnish stone. The facilities at hand for quarrying, the rates of transportation, and other items with reference to this quarry are given in the following statistical data.

Statistical Data.

Facilities at hand for quarrying: 1 3-hp. hoisting engine, 1 pump boiler, 3 channelers, 2 steam derricks, 2 hand derricks, 1 steam drill.

Average number of employees: 30 to 35.

Wages paid different classes of employees: Channelers, $2.00; hoisters, $1.75.

Cost of transportation: By rail, per 100.

St. Paul and Minneapolis	$.07
Chicago and Milwaukee	.10
Sioux City	.14
Omaha	.15
Des Moines	.16
Dubuque	.12½

Average value of each grade per cubic foot:

No. 1, mill....	$.40	Ton stone, No. 1.......$2.25 per ton
No. 2, mill....	.30	Ton stone, No, 2, $1.75–$2.00 per ton

Shipment for the past five years:

	1892.	1893.	1894.	1895.	1896.
Blocks	$11,250	$7,350	$2,920	$2,950	$2,500
Sawed	1,100	1,000	5,840	775	500
Ton	1,350	2,500	1,030	1,250	1,160
Rubble and bridge..	1,950	1,425	1,650	1,870	2,150
	$15,650	$12,275	$11,470	$6,845	$6,200

HARTLEY BROTHERS' QUARRY.

Historical.—The quarry owned by Hartley Bros. is located north of the Washburn Stone Co.'s quarry at Houghton. The first opening was made in 1885, but the stone from this opening did not prove satisfactory, and a second opening was made in 1887. In 1896, the company purchased a section of land from Babcock & Smith, which adjoins the latter company's quarry, and made a third opening. Up to 1896, the quarry was operated continuously, but in that year operations were continued only two months, and in 1897 the quarry was idle.

Quarry Observations.—Only one of the openings of this quarry was examined. This was the last one operated. The excavation is about 70 ft. long by 40 ft. wide. The depth could

not be ascertained on account of the water, which at that time almost filled the quarry. At the top there is a stripping of about 8 or 10 ft. of soil. The two benches exposed immediately underneath this are broken by irregular, diagonal joints, corresponding very nearly with the upper benches of Babcock & Smith's new opening.

An examination of a large number of scabble blocks taken from this quarry and piled up in the yard, shows that in places the stone is streaked with white, and contains occasional small white spots, which, however, are not sufficiently abundant to injure any large part of the stone. The texture is comparatively uniform. Small pebbles are irregularly distributed through certain blocks, but they do not materially affect the value of the stone. Cross bedding, which is characteristic of certain parts of nearly all of the quarries, occurs in certain of the blocks taken apparently from the upper courses in the quarry.

No statistical data of this quarry was obtainable, except what could be had by observation. It is thought that by proper handling and grading a large amount of good stone might be obtained from this property.

PRENTICE BROWNSTONE CO.

Historical.—The Prentice Brownstone Co.'s quarries are located at Houghton, a short distance south of the Washburn quarries. The property on which the quarries are located was selected for brownstone by Mr. Prentice, in 1857. Mr. Prentice was familiar with the shelly character of the Connecticut brownstone, which was so largely used for buildings in New York City and elsewhere. Appreciating the value of a brownstone, similar to that which he found in this section of the state, he concluded that if the stone could once be known, there would be a large demand for it, at the highest prices paid for brownstone. Accordingly in 1887, the Prentice Brownstone Co. was organized and incorporated under the laws of the state of Wisconsin, with a paid up capital of $1,250,000. During the same year the first opening was made. The company conducted an enormous busi-

LAKE SUPERIOR SANDSTONE.

Central High School, Duluth, Minn.

ness, until the financial depression of a few years ago, when it was forced into the hands of a receiver. The receiver, Mr. George N. Wiswell, is now operating the quarry on behalf of the creditors.

Quarry Observations.—Since operations were first begun the company has made four different openings. The first is about 150 ft. long, 100 ft. wide, and 25 ft. deep. The second is about 250 ft. long, 150 ft. wide, and 80 ft. deep. The third is 150 ft. long, 150 ft. wide, and 20 ft. deep. The fourth is 450 ft. long, 100 ft. wide, and 25 ft. deep. These openings are surrounded by 140 acres of land, all of which is controlled by the company.

At the time the quarry was inspected, in July of 1897, very little quarrying was being done. The largest opening was partly filled with water, and the character of the stone could only be determined from an examination of large scabble blocks, which were piled up in the yard. Two of the other openings were examined, and the stone was found to be very similar to that taken from the adjacent quarries. The largest opening consists of 13 benches. Below the sixth bench, at a depth of about 24 feet, there is a thickness of about 11 feet of No. 1 stone, from which the Prentice monolith, which was to have been erected at the World's Columbian Exposition, was cut. Below this there are about 8 feet of what has been classed as No. 2 stone. Below the No. 2 stone is a bed of blue tinted stone, from 5 to 6 feet thick, graded as No. 1. The remaining two or three benches are classed as No. 2 stone.

The other openings have not been developed to this depth, but as far as operations have extended, the stone is very similar to that of the first opening. The stone from all the openings is somewhat mottled, and contains occasional clay pockets and pebbles. The clay pockets are least abundant in the stone from the largest opening, and, with a little care, could be largely avoided. The beds are in some instances interlaminated with thin seams of clay. Black streaks occasionally occur in the rock, but they are not so conspicuous as to detract very materially from its value. Nevertheless wherever they become very

pronounced, they are indicative of weakness, and should be avoided.

General Considerations.—The stone from these openings should be carefully graded before being placed upon the market. No. 1 stone, which is quarried in large blocks, such as were observed in the yard, should be cut up into smaller dimensions and graded before being sold. The large scabble blocks frequently consist of first, second, and third grade stone, but unfortunately they are not sold as mixed stone, but either as all No. 1, or all No. 2.

The Prentice Brownstone Company has furnished an enormous amount of stone for buildings in the eastern, western, and southern states. In 1891 the output of the Prentice quarries aggregated 650,000 cu. ft. Many important buildings in the larger cities of the east and west have been constructed out of this stone. A partial list of these buildings and the date of their construction will be found at the close of this chapter.

The strength and durability of the brownstone from the Prentice quarry is shown in the tables given in Chapter VIII. After submitting the stone to a careful series of tests the conclusion reached is the same as that reached in the case of the stone from the other brownstone quarries. The No. 1 stone is in all respects suitable for building or other constructional purposes.

The enormous size of the blocks, which can be taken from these quarries, is well illustrated by the obelisk which was prepared for the World's Fair in 1892, but which unfortunately never left the quarry. This monolith of sandstone was about 110 feet in height; the base was about 10 feet square, tapering to 2½ to 3 feet at the top. This obelisk was presented to the World's Fair managers by Mr. Prentice, but owing to the apparently unsurmountable difficulties in transportation, the stone was never taken from the quarry. It contains some of the very best stone which the quarry produces, and is now being cut up and used for building purposes.

The quarry is well equipped with modern machinerv, piers, and tracks, as indicated by the following data.

LAKE SUPERIOR SANDSTONE.

1. Post Office, Ashland, Wis. 2. R. D. Pike's Residence, near Bayfield, Wis.

Statistical Data.

Amount of capital invested: $1,250,000.00.

Facilities at hand for quarrying: 1 45-hp., 3 25-hp., and 1 12-hp. engine, 8 channelers, 4 gang saws, 11 steam derricks, 2 hand derricks, 1 core drill, 6 steam boilers, machine shop.

Average number of employees: At present only 12.

Wages paid different classes of employees: $1.50 to $3.00.

Cost of transportation: By rail, $.07 to $.50 per cubic foot. About ⅛ less when by water.

Average value of each grade per cubic foot: No. 1, $.50; No. 2, $.30; No. 3, $.12.

Shipments for the past five years:

1892	No. 1....40,000	No. 2....100,000	No. 3.... 75,000
1893	No. 1....37,000	No. 2.... 60,000	No. ? ... 70,000
1894	No. 1....20,000	No. 2.... 40,000	No. 3....100,000
1895	No. 1.... 7,000	No. 2.... 4,000	No. 3.... 10,000
1896	No. 1.... 8,000	No. 2.... 6,000	No. 3.... 35,000

PIKE'S QUARRY.

The quarry owned by Capt. R. D. Pike is located on Van Tassell's Point, about 3½ miles south of Bayfield. This quarry was opened by Capt. Pike about 1888, and has been operated more or less each year up to 1897.

Quarry Observations.—Three openings have been made. One of these openings is immediately adjacent to the lake shore, where there is an almost vertical exposure of about 30 ft. With the exception of a single bed about 8 ft. thick, near the top, the stone at this place is soft and shaly. Many tons of stone have been quarried from this opening and used for pier and breakwater constructions. Some dimension stone might be quarried from the bed near the surface, but as a whole it is little suited for constructional purposes.

The other two openings have been made through beds, which are stratigraphically above those of the lake shore opening. The larger opening is immediately west of the station, and adjacent to the railroad. Its shape is irregular, as shown in Plate XXIV., Figure 2. The opening is about 80 ft. long by as many wide, and from 50 to 60 ft. deep. The best stone is taken from

the five lower benches, with an aggregate thickness of about 18 ft. Above this there are 15 ft. of No. 2 stone, which, in turn, is overlain with 5 or 6 ft. of shale. Above the shale there is exposed from 10 to 25 ft. of rubble and stripping. Of the 18 ft. of No. 1 stone at the bottom of the quarry, only the upper 10 ft. were exposed. The stone from these benches is remarkably free from clay pockets, only two or three being observed throughout the entire length of the quarry. In the 15 ft. of No. 2 stone, clay pockets are more abundant, giving the rock in certain parts a vesicular appearance, where the clay has fallen out. The upper courses, comprising from 10 to 30 ft. of stone, are suitable only for pier or foundation work.

The extent to which the stone in this opening is variegated, is uncertain, on account of the wash from above, which has given the quarry face a fairly uniform reddish brown color. An occasional black streak, similar to what has been noted in the stone from the previously described quarry, was observed. The stone which came under my observation was essentially free from pebbles.

The third opening is much smaller than the two just described, and is situated farther up the hill and north of the last. The stone is quarried from beds stratigraphically above those of the last opening. At a depth of from 4 to 6 ft., stone of excellent quality has been quarried. Below the first bench, the stone is even textured and practically free from clay pockets. A few agate pebbles are scattered promiscuously through the beds, but are so firmly cemented in the matrix, that they are not injurious. The sandstone is mottled with an occasional broad patch of white, which can only be avoided by proper cutting and dressing.

General Considerations.—The position of this opening is such as to suggest that it could be extended in any direction for a very considerable distance without encountering heavy stripping. This is always a decided advantage in the working of a quarry, and ought to command the attention of the operator.

The stone from Pike's quarry has been used in many buildings throughout the northwest, and is suited, when properly

LAKE SUPERIOR SANDSTONE.

Court House, Washburn, Wis.

graded, to all purposes for which brown sandstone is used. The quarry is equipped with all necessary machinery, including channelers, derricks, and engines.

The stone was thoroughly tested in the Survey laboratory, in the preparation of this report. The results are given in the tables in Chapter VIII., to which the reader is referred. The stone is equal in strength and durability to that which has been tested from other brownstone quarries of this area.

THE SOUTH SHORE AREA.

That portion of the Lake Superior brownstone region extending east from the northwestern corner of Douglas county, along the south shore of Lake Superior as far as Range 6, has been designated the South Shore Area. This sandstone belt varies in width from 4 to 10 miles. Development began almost contemporaneously with the opening of the first brownstone quarry in the Chequamegon area but later developments have not been so extensive, on account of the lack of transportation facilities. The first quarry was opened at Fond du Lac, Douglas county, in 1869, by Mr. Ingalls. Since the opening of this quarry, a number of other firms have operated, at various places along the lake shore, in this area, until up to the present time quarries have been opened and operated at six different places.

Quarry Observations.

The brownstone from this area corresponds very closely in color and texture to that which is quarried in the Chequamegon area. The range of brown tints is probably somewhat wider than those in the Chequamegon stone. Certain beds have a decided bluish tone, while in others the color is a cheerful red. (See Plate XXXIV.)

The natural outcrops indicate that the stone disintegrates very slowly, and that the color is permanent. In many places the stone is covered with lichens, giving some indication of its durability. The texture of the rock is essentially the same as that which has been described in connection with the Chequamegon

area. In certain of the quarries it exhibits the same inperfections that the stone from the previously described area does. The stone in certain of the quarries is affected more or less with clay pockets, but they are apparently less abundant here than in the Chequamegon quarries. In many of the openings, the stone is partly streaked or spotted with white, but in uniformity of color the stone compares very favorably with that of the previously described area. Pebbly layers may be observed in these quarries, as in the quarries of the Chequamegon area. Certain of the beds show the cross bedding, so common to nearly all sandstone.

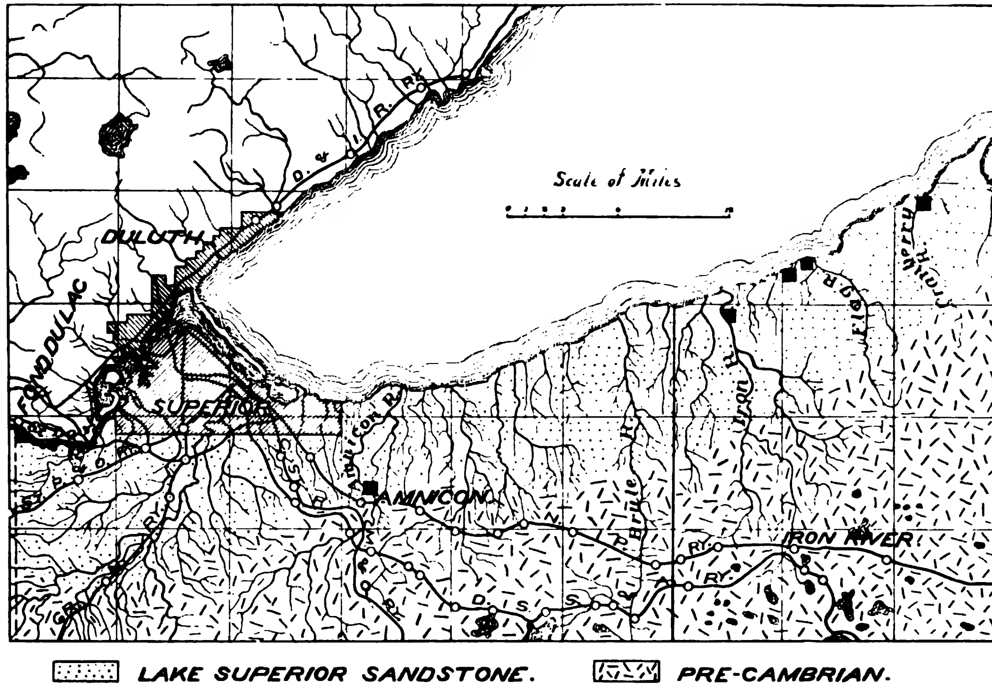
The jointing planes in the sandstone are not sufficiently close or regular to be either useful or especially harmful in quarrying. The main joints strike N. 55° W., and about north and south. Stone of any desired dimensions can be quarried.

Laboratory Examination.

The Dressed Sample.—The samples, which are displayed in the laboratory of the Survey, are excellent examples of the fine hammered work, which the stone is capable of taking. (See Plate LVIII.) Probably no sandstone takes a better rock face or hammer dressed finish than does the brownstone from this or the Chequamegon area.

Microscopical Examination.—The microscopical examination of thin sections of the sandstone from this area, show that the individual grains are somewhat better rounded than those of the sandstone from the Chequamegon area. As would naturally be supposed, the grains of sand, in the different sections examined, differ considerably in size, but in general, they correspond quite closely with those of the Chequamegon sandstone. (See Plates LXIV. and LXV.)

The sandstone consists essentially of rounded or sub-angular grains of quartz, mingled with which is an occasional feldspar individual, and a very small amount of clay. Some of the quartz individuals have been enlarged, and the grains are generally firmly bound together by a siliceous cement. Each of the individuals is coated with a thin film of reddish brown iron



SOUTH SHORE AREA.

oxide. Small irregular areas of magnetite occasionally occur in the midst of the hematite, suggesting that the latter may, in some instances, be an alteration product of the former.

The microscopical examination shows the rock to be essentially the same as the sandstone from the Chequamegon area. The large percentage of quartz, the relatively small amount of argillaceous material, and the siliceous cement all point to the relative stability of the rock.

Chemical Analysis.—The following chemical analysis of the sandstone from the Port Wing Quarries, by Prof. W. W. Daniells, shows that the rock is essentially free from those elements which result in rapid disintegration.

$Si\ O_2$	89.33
$Al_2\ O_3$	6.05
$Fe^2\ O_3$	1.41
$Ca\ O$	trace
$Mg\ O$	trace
$K_2\ O$	2.12
$Na_2\ O$	0.59
	99.50

Physical Tests.—The result of the physical tests as conducted in the preparation of this report are given in the tables in Part II., Chapter VIII. The average specific gravity of the sandstone from this area corresponds very closely with the result obtained for the sandstone of the Chequamegon area, being 2.629. The porosity of the sandstone averages 18.42 per cent., which also corresponds, quite closely, with the porosity of the sandstone of the previously described area. The ratio of absorption is 8.568 percent., which is a little less than the percentage obtained for the samples from the Chequamegon area. It will be noticed by examining the tables that the lower average porosity and the lower average ratio of absorption is due mainly to the two samples from the Duluth Brownstone Co.'s quarry, in which the porosity runs about 10 per cent. lower than in any of the other samples of brownstone tested.

The crushing strength of the stone from this area is given in Chapter VIII., Table II. The average result of eight tests gave

a crushing strength of 5,272 lbs. per sq. in., which corresponds very nearly with the tests made on samples from the other brownstone area. The transverse strength tests are given in Table III., of the same chapter, and show an average strength of 444.9 lbs. per sq. in. This average is lower than the same tests of the samples from the other sandstone area, but is still close to the mean modulus of rupture of ordinary sandstone.

Samples from this area were subjected to freezing and thawing, with the results indicated in Chap. VIII., Tables VI. and VII. It will be noted that the average loss of weight after 35 days' exposure, on six samples, weighing about 300 grams, was only .44 of a gram. The loss in strength due to alternate freezing and thawing averaged 18 lbs. per sq. in. The samples from one quarry tested 912 lbs. per sq. in. higher, and those from the other quarry were 930 lbs. per sq. in. lower.

The result of extreme heat on the sandstone samples from this area indicates, with one exception, that at a temperature of 1,200° to 1,500° F. the strength of the stone is essentially gone. The brown sandstone from the Duluth Brownstone Co.'s quarry is apparently an exception to this rule. To all appearances, the sample from this quarry was little injured after it had been heated to a temperature of 1,400° to 1,500° F. In no case were the samples fractured, but when cooled, most of them were found to be so weakened that they could be crumbled between the fingers. When scratched, the cubes that were heated emitted a rasping sound, similar to that emitted by a brick when it is scratched.

General Considerations.

The results of the laboratory tests bring us to essentially the same conclusions, with reference to the sandstone of this area, as were reached in the discussion of the Chequamegon sandstone. All the samples tested indicate a sufficient strength and durability to recommend them for constructional purposes. The stone is sufficiently strong for the most massive buildings and bridges, and works easily and readily and with good effect under the chisel. The durability of the stone can scarcely be

LAKE SUPERIOR SANDSTONE.

... Building, University of Wisconsin, Madison, Wis.

questioned, while the capacity it has for resisting extreme heat up to 1,000° F. makes it one of the best stones on the market for buildings in large cities.

Description of Individual Quarries.

The brownstone quarries of this area are as follows: The Duluth Brownstone Co.'s quarry, at Fond du Lac, the Port Wing quarry, at Port Wing, owned and operated by Miller Bros. & Johnson, the Arcadian Brownstone Quarry, at Amnicon, the Iron River Quarry, near the mouth of Iron River, the Flag River Quarry, near the mouth of the Flag river, and the Cranberry River Quarry, near the mouth of the Cranberry river. Of these six quarries only the first four are now operated.

THE DULUTH BROWNSTONE CO.

The Quarry operated by the Duluth Brownstone Co. is located on lots 1 and 2, Sec. 6, T. 48, R. 15 W., in Douglas county. The quarry was opened in 1869, by Mr. Ingalls, and has been operated each year since, with the exception of a period of twelve years from 1873 to 1885. Seventeen years after the quarries were opened by Mr. Ingalls, they were purchased by the Duluth Brownstone Co., by whom they have been owned and operated up to the present time. The company is a stock company, of which Mr. J. H. Crowley, of Duluth, is President. The company has a capital of $30,000, and not less than $30,000 or $40,000 worth of stone has been taken from the different openings.

Quarry Observations.

This is the only quarry in the Lake Superior region from which both brown and white sandstone are quarried. A very good quality of buff, as well as brown sandstone is obtained at this quarry. Quarrying operations have been conducted at three different places along the bluffs adjacent to the St. Louis river. The first is 150 ft. long, 60 ft. wide, and 35 ft. deep; the second is 300 ft. long, 70 ft. wide, and 40 ft. deep; the third is 200 ft. long, 100 ft. wide, and 35 ft. deep.

Surrounding these openings the company controls 52 acres of land. Two of the openings have not been worked for about 8 years.

The one which is now operated has a face of about 250 ft., but on account of the heavy stripping in the middle of the quarry, it is now being worked only at the ends. The depth of the stripping varies from 3 to 8 feet. The height of the face from the base to the stripping is 40 ft. The forty foot face consists of nine or ten beds, ranging from 2 to 5 feet in thickness. The beds are not continuous throughout the entire quarry, but break up into two and sometimes three, as they are followed from one side to the other. The joints at this place, which strike about east and west, and north and south, are sufficiently close to be used to advantage in quarrying. Besides the joints, other irregular, nearly horizontal seams, traverse the quarry in various directions. The size of the blocks are limited to dimensions of about 6 ft., by 8 ft., by 5 ft.

The brown sandstone has a bluish or purplish tint, and is often spotted and streaked with white. The first four feet at the top of the quarry is rubble. The beds immediately below the rubble differ very little either in texture or color, until the lowest bench, consisting of six feet of buff colored stone, is reached. Thin seams of red and green clay occur between the beds, while clay pockets are occasionally met with within the beds themselves. Nowhere in the quarry has the stone an absolutely uniform color, and if it were to be classified according to the specifications laid down with reference to the stone from the Chequamegon area, it would necessarily be graded as No. 2 and No. 3.

General Considerations.

The stone is quarried very cheaply, loaded upon scows, and transported by tugs to Duluth, where it is sold mainly as ton stone. The quarry is not very extensively equipped with machinery. The stone is quarried mainly by blasting and wedging, and is lifted by means of horse power derricks onto the scows used for transportation.

The samples from this quarry gave the highest physical tests of any of the samples of brownstone. The porosity is low, the specific gravity about normal, and the results of alternate freezing and thawing and extreme heat exceptionally favorable. The crushing strength was also above the average.

The important markets for the stone from this quarry are Superior, Duluth, Minneapolis, and St. Paul. The cost of transportation by water from the quarry to Duluth is 1¼ cents per hundred. By rail, from Duluth to Minneapolis and St. Paul, the rate is 6 cents per hundred, making a total of 7¼ cents per hundred for transportation to these markets.

The first buildings which were constructed from this stone, as far as known, are the Clark and Hunter blocks of Duluth. Some of the more important structures which have since been constructed out of this stone will be found in the list appended to this chapter.

The quarry has not been worked very extensively during the last few years on account of the prevailing business depression. The company is prepared to furnish brown and white mill blocks for building, as well as ton stone and rubble for pier, footing, and bridge purposes.

Statistical Data.

Amount of capital invested: $30,000.

Facilities for quarrying: 4-horse power derricks.

Average number of employees: 10 to 70.

Wages paid different classes of employees: $1.50.

Cost of transportation: By rail, Duluth and Superior, $5.00 to $8.00 per car. By water, one half of the above.

THE PORT WING QUARRY CO.

The quarry of the Port Wing Quarry Co. is located at Port Wing, on the south shore of Lake Superior, about thirty miles from Superior. The quarry is owned and operated by Miller Bros. & Johnson, and was opened in the spring of 1895. It has been operated each year since, during the period between April and November. The quarry consists of one opening, about

which the company owns 120 acres of land. The quarry is on the lake shore, about a mile and a half directly west of the village of Port Wing. From this place the sandstone outcrops almost continuously for a distance of two miles to the west.

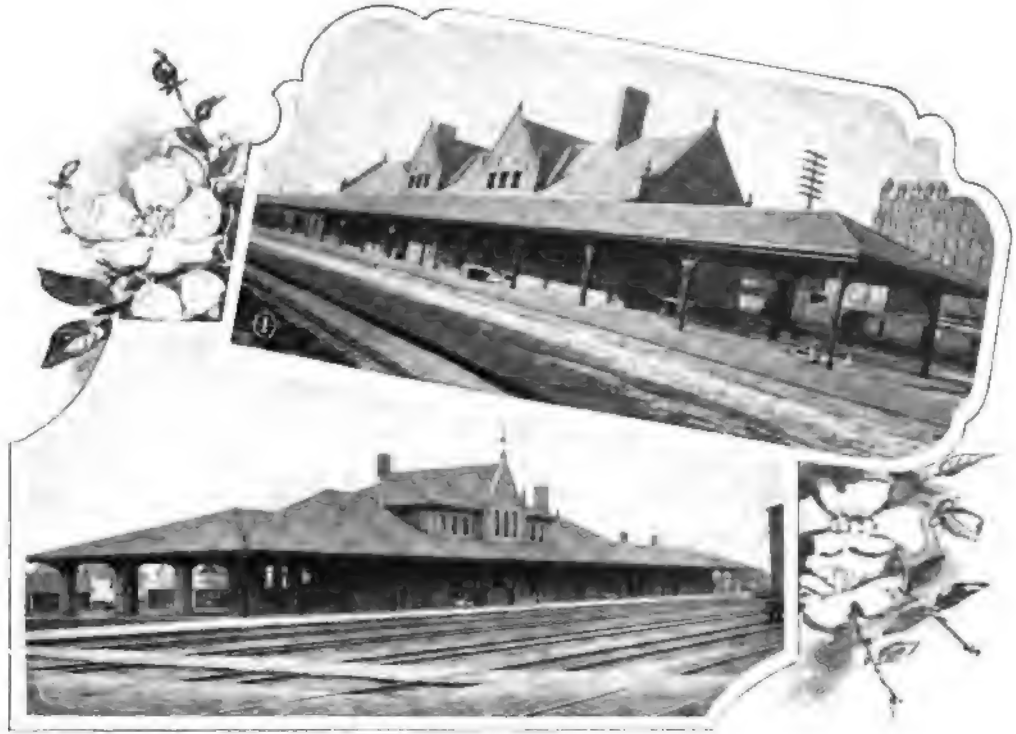
Quarry Observations.

The quarry is not large, having a face from 250 to 300 feet long, and about 8 feet deep. The stripping is about 2 or 2½ feet thick, and will probably not increase for a considerable distance back of the present face of the quarry. The beds are not of uniform thickness, but vary in different parts of the quarry. The jointing planes strike about N. 55° W. and north and south, but are not sufficiently close to be either useful or harmful in quarrying. Irregular inclined joints occur in this quarry, as elsewhere, but are so far apart that stone of practically any required dimensions can be obtained.

The quarry consists essentially of one bench, which varies from 6 to 8 ft. in thickness. The main part of the bed, comprising about 200 feet of the face, is massive and entirely free from white streaks and spots. At the east end, for a distance of about 15 feet, the rock near the surface is much cracked and broken, and is used mainly for rubble. At the west end, for a short distance, the stone is distinctly laminated, and somewhat streaked with white.

Not a single clay pocket could be found anywhere in the quarry after a most careful search. The beds contain no pebbles, and it is worthy of notice that this is the only quarry, thus far examined, in which certainly 95 per cent. of the stone is No. 1. Nearly the entire output of the quarry may be so graded.

The color of the stone is not the same in all parts of the quarry. A portion of the bed, mainly at the top, at the east end, is mottled with small dark brown spots due to segregations of iron oxide. Mottling, similar to this, is characteristic of the stone from Marquette, Mich., and is known as "rain drop" sandstone. This so-called "rain drop" sandstone is equal to the very



LAKE SUPERIOR SANDSTONE.

1. C., St. P., M. & O. Ry. Depot, Duluth, Minn.
2. C., St. P., M. & O. Ry. Depot, Eau Claire, Wis.

best No. 1 stone and at one time it had a very large sale in Chicago and other cities. There appears to be no regularity in its occurrence, as it occurs mainly in occasional small bands in different parts of the quarry. The stone is equally as strong as the more abundant, uniformly colored, reddish brown stone. The color of the "rain drop" stone is nicely illustrated in Plate XXXIV., Figure 2.

The texture of the rock is uniform throughout. Occasionally one observes faint black streaks, indicative of former bedding planes, but these markings are very inconspicuous.

General Considerations.

The possibilities for obtaining No. 1 stone could not be better than they are at this place. The face of the quarry exposes stone which is essentially free from white streaks and spots, and entirely free from clay pockets. These two imperfections, which have so militated against the brownstone from the Chequamegon area, and other quarries along the south shore, have not become a consideration at this place.

By reference to the tests of durability and strength of the brownstone from this quarry (See tables Chapter VIII.), it will be observed that the stone is equal in most respects to that from the other quarries of this or the Chequamegon area. The strength and durability of the rock are sufficient for all important buildings.

The quarry is equipped with all necessary machinery, including engines, derricks, piers, gang saws, etc. In the short time that the quarry has been operated, the stone has found a market in Wisconsin, Minnesota, North and South Dakota, Canada, Iowa, Illinois, and Michigan. The important structures into which the stone has gone will be found in the list appended to this chapter.

Statistical Data.

Amount of capital invested: $1,000.00.

Facilities at hand for quarrying; 1 45-hp. engine, 1 channeler, 2 gang saws; 2 steam derricks.

Average number of employees: 7.

Wages paid different classes of employees: $1.50 to $1.75.

Cost of cutting and dressing per cu. foot. Sawn, $.15; ribbed, $.15; pointed, $.02; bush hammered or chiseled, $.20.

Cost of transportation: By rail, $.12 per cu, ft.; by water, $.02 ½ per cu. ft.

Average value of each grade per cubic foot: No. 1, $.35; No. 2, $ 30; ton stone $2.20 to $2.50 per ton.

Shipments for the past three years:

1895	25,000 cu. ft.
1896	37,000 cu. ft.
1897	50,000 cu. ft.

THE FLAG RIVER QUARRY.

The Flag River Quarry is located on the south shore a short distance west of the Port Wing quarry, near the mouth of the Flag River. The property is owned by Col. Isaac H. Wing, of Bayfield, and was leased in 1889, by Mr. Miller, of Duluth, who opened the quarry under the name of the Flag River Brownstone Co. Later the name was changed to the Flag River Quarry. In 1894 Mr. Miller's lease expired, and since that time the quarry has not been in operation.

Quarry Observations.

The quarry consists of two openings located about forty rods from each other. The opening farthest east has not been worked for five years but general appearances indicate that a considerable amount of stone was at one time quarried at this place. No stone has been quarried lower than the lake level, all stone having been taken from two benches with a total thickness of ten feet. The stripping is heavy at this point, consisting of from ten to twelve feet of clay.

The stone has a generally uniform brown color, with the exception of certain portions immediately adjacent to shear zones, where the color is yellow. These shear zones are vertical, and strike N. 10° W. The space between the walls is filled with a soft arenaceous clay, resembling the mud seams occurring in the Niagara limestone at Joliet, Ill. The face of the quarry at this place shows no injurious clay pockets, although the bed immedi-

ately below the lake level contains an abundance of them. Small pebbles are scattered promiscuously through most parts of the bed.

The second opening has not been worked as far from the shore as the one just described. The stripping at this place has a thickness of 10 to 12 ft., while the face of the quarry has a maximum depth of 16 ft., of which 6 ft. is below the floor of the first opening. The face of the opening is somewhat irregular and extends along the shore for a distance of about 200 ft.

The color of the stone is less uniform than in the first opening, being streaked in certain places with white. These variegated layers are also cross-bedded, and contain small clay pockets and pebbles. The lower beds are more uniform in texture and color than the upper and have apparently furnished the best quality of stone.

General Considerations.

The stone from the Flag River quarry was tested in connection with the samples from the other brownstone quarries. The results may be found in the tables in Chapter VIII. In all these tests the results proved very satisfactory, confirming our previous general conclusions regarding the adaptability of the brown sandstone for all constructional purposes.

As will be seen in the list of buildings appended to this chapter, the stone from this quarry has been used in some of the most important brownstone structures of the northwest. The machinery formerly used in quarrying has been largely removed, and the quarry is at present essentially unequipped.

IRON RIVER RED SANDSTONE CO.

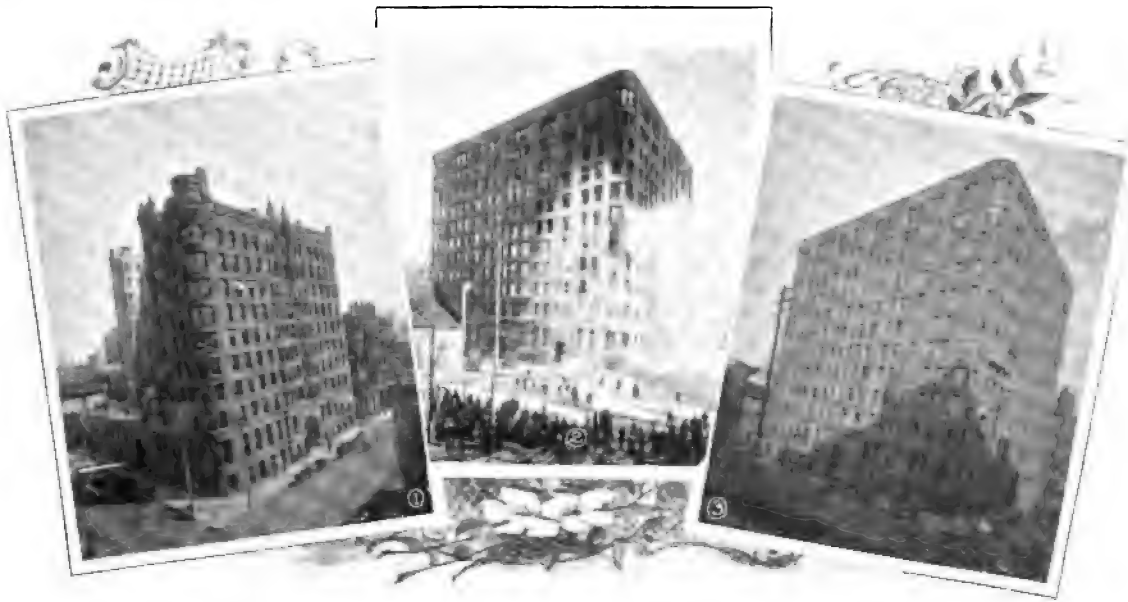
The quarry of the Iron River Red Sandstone Co. is located in Bayfield county, about a mile above the mouth of the Iron river. The first opening was made in 1892 by the Iron River Brownstone Co. Shortly after this, the ownership was transferred to the Iron River Red Sandstone Co., by which company the quarry was operated up to 1897, when it was leased for one year to the Bourgeault Stone Co. The quarry is operated at

present by the Iron River Red Sandstone Co., of which Mr. A. C. Titus, of Superior, is President, and Mr. W. G. Crosby, of Duluth, Minn., is Secretary and Treasurer.

Quarry Observations.

The quarry comprises three different openings, which are respectively 300 feet long, 100 feet wide, and 50 feet deep; 100 feet long, 40 feet wide, and 40 feet deep; and 100 feet long, 50 feet wide, and 20 feet deep. They are situated adjacent to the river, at a place where the natural outcrops rise to a height of from 30 to 60 feet above the river. The 120 acres adjacent to the quarry, owned by this company, have been shown by direct borings to be underlain at a little depth by sandstone similar to that which outcrops along the banks of the river.

During the season of 1897, only the opening farthest south was being worked, the others having been abandoned on account of the heavier stripping. The stripping at the top of this opening is about 10 feet deep. The four beds immediately underneath the stripping are respectively 2½ feet, 2½ feet, 2 feet, and 1 foot in thickness, the three upper being sold as No. 2 ton stone, and the lowest as rubble. These beds contain a very few, small clay pockets, the lower beds being classed as rubble, on account of white streaks and lamination. The 6 foot bed immediately below the rubble is one of the best in the quarry. It is uniform in texture and color, free from clay pockets, and shows only an occasional dark colored pebble. The next 3 feet are shaly, contain clay pockets, and the stone is very inferior. It is classed as rubble. The stone in the next 16 feet is practically free from injurious clay pockets, white spots, or streaks, but in places is cross-bedded and discolored by black or deep brown streaks, on account of which it is classed as No. 2. The stone from the next three feet is laminated, and streaked with black along the horizontal and cross-bedding planes, and is classed as No. 3 block. The stone from the remaining 5 feet is mostly clear stock, and is quarried for No. 1 block. In general, the stone from this opening, with the exception of the rubble beds, is free from injurious clay pockets, pebbles, or white mottling. The color is



LAKE SUPERIOR SANDSTONE.

Lumber Exchange, Minneapolis, Minn.

1. Before the fire. 2. At the time of the fire. 3. As repaired after the fire.

a reddish brown, somewhat brighter than that which is ordinarily obtained from the brownstone quarries.

The second opening (See Plate XXIV., Fig. 1,), which is adjacent to the river, and a few rods north of the south opening, is the largest of the three. The earthy stripping has a maximum thickness of about 12 feet, immediately underneath which are 10 ft. of rubble. Below the rubble occur about 34 ft. of block stone, grading Nos. 1, 2, and 3. The quality of the stone differs in each bed, and in different parts of the same bed. The dimensions are practically unlimited, the largest block thus far quarried being 10 ft. by 16 ft. by 52 ft.

The upper beds are somewhat mottled with white streaks and spots. The dark streaks, noted elsewhere, occur occasionally along the sedimentary planes. Certain of the lower benches are almost free from clay pockets, and contain a large percentage of No. 1 stone. The 16ft. at the bottom of the quarry comprise the best stock, but at irregular intervals narrow bands of small clay pockets run parallel to the bedding, which necessitate sawing and grading the stone. In general, the stone from this opening does not show up as well as the stone in the opening first described.

General Considerations.

The tendency for the sandstone of this quarry to be laminated, is more marked than in other quarries of this area. The presence of a considerable amount of laminated stone means that the stone should be judiciously graded, and that care should be exercised on the part of the builder, to see that the stone is laid on the bed in the wall.

The quarry is prepared to furnish three grades of stone in scabble dimension blocks, suitable for building, pier, breakwater, and bridge work. The facilities at hand for quarrying are such that the cost of exploitation ought to be reduced to a minimum. Channelers, steam drills, and steam derricks are used in most of the work. The stone is loaded onto cars at the quarry and transported by means of a gravity road to the lake, where the company owns an excellent dock. From here it is

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shipped by scow to the dock at West Duluth, and from thence it is transported by rail or water to the various markets.

The Iron river, on the banks of which the quarry is located, would furnish an excellent water power, which could be used to advantage in operating the quarry. The river might be harnessed at this place with little difficulty, and made to furnish all the power needed to operate the quarrying machinery.

The stone from this quarry was first used in Duluth, but the first important structure built of this stone was one of the buildings of the Minnesota University. A few of the important structures into which the stone from this quarry has gone, and the date of sale of the stone, are given in the list appended to this chapter.

Statistical Data.

Amount of capital invested: $100,000.00.

Facilities at hand for quarrying: 1 engine, 50 hp., 2 channelers, 4 steam derricks, 2 hand derricks, 1 steam drill.

Average number of employees: 15 to 40.

Wages paid different classes of employees per day: $1.50 to $2.00.

Cost of cutting and dressing stone per square foot: Sawn, $ .70; ax-hammered, $ .80; bush hammered or chiseled, $1.00; polished, $1.00.

Cost of transportation: $ .10 to St. Paul and Minneapolis, $ .28 to Manitoba, $ .18 to Dakota.

Average value of each grade per cubic foot: No. 1, $ .50; No. 2, $ .30; No. 3, $ .20.

ARCADIAN BROWNSTONE COMPANY.

The quarry of the Arcadian Brownstone Co. is located at Amnicon on the Northern Pacific Ry., about 10 miles southeast of Superior. It was opened in 1886 by the company now owning the quarry, and has been operated each year since. The company owns 10 acres of land surrounding the opening from which over a million cubic feet of stone have been quarried.

Quarry Observations.

At the time the quarry was visited early in the summer of 1897, it was filled with water, which prevented an examination

of the different beds. The stone is graded into Nos. 1, 2, and 3 block and ton stone, and rubble. The No. 1 block is free from clay pockets and white streaking and is said to occur in beds from four to five feet in thickness. Nos. 2 and 3 are more or less imperfect, the lowest grade often being largely mottled with white.

The No. 1 stone has a very pleasing color and a uniform texture. It carves nicely and is well suited for general building purposes. Any required dimensions may be obtained, either in scabble dimension blocks or sawed. The poorer grades have been furnished mainly for basements and piers.

General Considerations.

The quarry is fully equipped with machinery for quarrying, and employs from twenty to thirty men, when running full force. A spur runs from the Northern Pacific Ry. to the quarry so that the stone may be loaded from the quarry directly onto the cars. The stone from this quarry was first used in Chicago, but since then has found its way into many other important markets, among which may be mentioned Superior, Duluth, St. Paul, Minneapolis, Sioux City, and Omaha. A number of the more important buildings, in the construction of which the stone from this quarry has been used, are given in the list appended to this chapter.

Statistical Data.

Amount of capital invested: $40,000.00.

Facilities at hand for quarrying: Quarry is fully equipped with engines, channelers, derricks, saws, and other necessary, miscellaneous machinery.

Average number of employees: About 20.

Wages paid different classes of employees: From $1.50 to $3.00 per day.

Average value of each grade per cubic foot: No. 1, $.50.

CRANBERRY RIVER QUARRY.

The Cranberry River Quarry, located on the lake shore at the mouth of the Cranberry river, was opened about six or seven years ago by Quinby and Omeis. The quarry was operated for

14

about six months prior to the failure of the company, and furnished a limited amount of stone for basements, curbing, and building purposes. Several buildings were constructed out of the stone from this quarry, and a small amount of the stone was used in the construction of the Duluth High School. The quarry has been idle for several years, the machinery having all been sold and removed from the quarry. The property is now in the possession of the Lake Superior Brownstone Company.

GENERAL RÉSUMÉ.

EVIDENCES OF STRENGTH AND DURABILITY.

It is evident to one who has examined the Lake Superior sandstone, in the quarry and in the buildings, which have been constructed therefrom, that it is admirably suited for the uses to which it is being placed. The stone has been known but a little over a quarter of a century, as a building stone, the first building having been constructed in 1870. During this short period, hundreds of the finest buildings in the north central states have been constructed from Lake Superior brown sandstone. No richer, more beautiful, or more durable structures can be found, than those built from No. 1 Lake Superior brownstone. The color is permanent, frost does not easily injure the stone, and it is only destroyed by the most intense heat. But buildings, as perfect and fresh today, as they were when first constructed, need not be taken as conclusive evidence of the permanent character of the rock. The results of an inspection of the stone in the natural outcrop, where it has been exposed for perhaps many thousand years, further testify to its durability and permanence. Even this evidence, however, would not be conclusive without the laboratory tests. The many tests which were made in the preparation of this report fully substantiate the conclusions reached through the observations on buildings and quarries. Every evidence points to the unquestionable fitness of the best brownstone for the finest kinds of constructional work.

1.

2.

LAKE SUPERIOR BROWN SANDSTONE. FROM SOUTH SHORE AREA.

No difficulty, as a rule, is experienced in quarrying blocks of very large dimensions. The quarries are generally equipped with the best machinery, and facilities for transportation, either by rail or by boat, are good. The wages paid working men are comparatively uniform.

CAUSES OF THE PRESENT INACTIVITY.

The question then arises as to what is the cause of the past and present general depression in the brownstone industry of this region. There are a number of causes which have contributed to the present inactivity, chief among which may be mentioned (1) general business depression, with an accompanying cessation of building; (2) change in fashion; (3) unnatural competition among brownstone operators.

It is well known that the panics of 1891 and 1893 occasioned a decided cessation in all building operations, and especially decreased the sale of expensive materials, such as stone. Consequent upon the panic certain of the companies became financially involved, and this, combined with the lessened demand, hastened the destruction of the brownstone industry. About this time the fashion changed and the demand was turned from dark to light colored stone. Brownstone from the Connecticut and Pennsylvania quarries had been used for many years and was known all over the country. Many of the buildings constructed out of Connecticut brownstone had begun to look shabby on account of improper handling and laying, and the somber rows of brownstone buildings had become monotonous to the eye. The Indiana Bedford limestone was on the market to supply the rising demand for light colored stone, and the operators have pushed their stone into the market, until today it is probably the most extensively used building stone in this part of the country.

The third cause for the decline in the brownstone industry is found in the unnatural competition engaged in by the local operators, at a time when the demand for brownstone was at its height. Quarry operators indulged in cutting prices, and, in order to maintain their margin of profit, they either mixed or

lowered the grades, by which a considerable amount of vastly inferior stock was placed upon the market, and sold for No. 1. stone.

Further, it may be said that there has apparently been no attempt to regulate the use of the different grades of stone. Rubble has been placed in the fronts of buildings, where nothing but No. 1 stone should have been allowed. Every front constructed out of inferior stone militates, not alone against the output of the quarry, but against that of the entire region. Contractors and builders can purchase inferior stone at a lower price than they can No. 1, and by its use secure contracts that they otherwise could not get. In this way, there have been constructed, in different parts of the country, buildings which in no wise represent the quality of stone that may be obtained from the Lake Superior quarries. Yet competing operators gladly point to these buildings, constructed from inferior stone, as representative of Wisconsin brownstone.

Architects and builders should know definitely the grade of stone which is to be used in the building to be constructed, and they should demand that the grade be maintained. Quarry operators ought to refuse to sell inferior stone, if it is to be used in places where it will be conspicuous, as an example of their output. To sell knowingly inferior stone to be used in the fronts of magnificent buildings is the most damaging thing that can happen to the brownstone industry. It has occurred in the past, but it is to be hoped that these examples will suffice for the future.

UNIFORM GRADING.

Apparently there is no uniformity among the different operators with respect to what constitutes the different grades of stone, and it becomes necessary for one to know exactly the condition of the quarry, and the standard of the quarryman, in order to know the quality of stone which is represented by any one grade. It appears that a recognized, uniform grading should be established in this region, so that when No. 1 mill blocks are spoken of, it will be unnecessary for the person ad-

dressed to ask, the meaning of that grade. No. 1 mill blocks and No. 1 ton stone are considered by the quarrymen to be the same grade, with the exception that the latter is sold in rough, angular blocks, while the former are either sawn or scabbled. The same is true of No. 2 mill blocks and No. 2 ton stone. The term rubble is generally applied to any rough stone of irregular dimensions, of all grades from No. 1 to No. 3. No. 1 mill blocks are generally known as stone which is free from large blemishes of white, uniform in color, with four square sides and sound. No. 2 mill blocks are generally known as that stone not sufficiently clear and free from white to grade No. 1, but sufficiently good to make excellent rock face work.

The stone from these quarries is seldom graded any closer than No. 1 and No. 2 mill blocks, or No. 1 and No. 2 ton stone, but it appears quite necessary, in order to establish uniformity, that three grades, instead of two, should be recognized. It will be noticed that in the above customary basis for grading stone, no mention is made of clay pockets or pebbles, yet it is eminently fitting that these irregularities should be considered in grading the stone. In accordance with this belief, I desire to submit the following as a more rational basis on which to grade the stone. No. 1 mill blocks ought to be known as that stone which is free from large blemishes of white, uniform in color, free from clay pockets and pebbles, with four square sides, and sound. No. 2 mill blocks ought to be known as that stone which is sufficiently free from clay pockets to admit of perfect rock face work, and sufficiently free from white to give general uniformity of color and structure. No. 3 mill blocks should be known as that stone which is sound, and sufficiently free from clay pockets as to admit of ordinary rock face work. No. 1, No. 2, and No. 3 ton stone should be known as stone equal in quality to Nos. 1, 2, and 3 mill blocks, but of irregular shape, the pieces weighing from ½ to 3 tons. Rubble should be known as that stone which is broken into such sizes as can be readily handled by one or two men, of various grades, and suitable for foundation work. If the stone from this region were carefully graded, upon a basis similar to this, there would be less confusion and difficulty on

the part of contractor and builder in knowing the character of stone he was purchasing under specifications for a certain grade.

SAWING AND DRESSING.

Operators in this region have been uncertain as to the advantages to be derived from sawing the stone at the quarry, but the answer is not very difficult when the necessity for grading the stone is considered. Sawing appears to be almost a necessity for economical working. It has been observed that much No. 1 stone could often be obtained from No. 2 scabble blocks, provided the stone could be sawed at the quarry. Likewise the No. 1 blocks occasionally contain stone, which would be graded No. 2, if sawed. The blocks showing white streaking and blotches could often be so cut as to leave a uniformly colored face free from white. In this and many other ways it appears that the saw can be used to advantage in connection with the quarry.

PRICE.

The greater strength and durability of the Wisconsin brownstone over that from other localities, as indicated by the laboratory tests, and the greater difficulty with which the stone is cut, dressed, and carved, has resulted in somewhat higher prices for the product. A higher price for the dressed stone places it on the market at a considerable disadvantage, for it is a difficult matter in these days to make a purchaser understand that sometimes "the dearest stone is the cheapest in the long run." But in spite of the greater expense of working the brownstone, it is now sold in the market at prices which furnish lively competition for operators in less durable stone. The cost of cutting and dressing the brownstone is given below, the figures being taken from current prices in 1897.

The Bourgeault Stone Co. of Duluth quotes the following prices for cutting and dressing stone:

Sawn	$.70
Ax-hammered	.80
Bush hammered or chiseled	1.00
Polished	1.00

The Superior Cut Stone Co. of Superior gives the following prices:

Sawn	$.70
Ribbed	.80
Pointed	.70
Ax-hammered	.60
Pointed	.70

Bass Island Brownstone Co.:

Sawn	$.20

Ashland Brownstone Co.:

Sawn	$.25

TRANSPORTATION.

Finally, the transportation rates have been such that the eastern product has had an advantage over the product from Wisconsin. Freight rates are a considerable factor in the success of a quarry, and where discriminations are made between east and west bound freight, it works an injustice to the less favorably situated quarries.

SUGGESTIONS.

In order that the brownstone may not fall into disrepute, and that subsequent development may be permanent, certain cautions should be observed relative to extracting, cutting, and laying the stone, which it may not be out of place to mention. In the first place, blasting should never be resorted to as a means of quarrying the stone. The stone should only be quarried during those months when there is no danger from freezing. This time naturally varies with the season, but it is safe to say that the stone may be injured when quarried earlier than April 15th or later than November 15th.

Before being placed in a building, the stone should at all times be thoroughly seasoned. It is very true that stone from certain of the brownstone quarries has been placed, unseasoned, in positions where the liability to injury was very large, without material injury, but this is not a safe practice and ought to be avoided.

It is difficult for the ordinary observer to detect sedimentary

planes in much of the brown sandstone, but the man who cuts the stone can easily distinguish the original position of the stone in the quarry. Whether the sedimentary planes are prominent or not, one should never lay the stone on edge in a building. This is the only safe rule to observe.

The judicious use of different shades of brown will add much to the appearance of a building. Each block of stone ought to be considered in its relation to every other, not only in its shape and position, but also with reference to its color. There is a variety of shades of brownstone, and each one may be so used, as to either enliven or deaden the effect of the wall. The mottled stone may be used in places so as to produce a fantastic and varied effect, and if judiciously selected and laid as designed, it often proves very pleasing.

For use in the business portions of large cities, there is no more suitable color than reddish brown. It shows less than any other, the streakings of soot and dirt which are so conspicuous on the walls of buildings constructed out of light colored stone. For residence fronts the brownstone cannot be surpassed for richness of color. The brighter shades, although not light and flashy, are sufficiently brilliant to give life to the stone.

The quarrying of brownstone is one of the important industries of northern Wisconsin, but, like all other new enterprises in a rapidly growing country, has met with reverses. It is believed that the uncertain period has passed, and that a new era has been entered upon, in which the development may not be as rapid as in the past, but it will be more certain.

Appendix.

On the following pages will be found a partial list of buildings constructed out of Lake Superior brownstone. In some of them the parts constructed out of brownstone are given, but in others no attempt has been made to give this data. The date of erection of the building, the location, and the quarry from which the stone was taken, have also been inserted. Certain of these buildings have been shown in the preceding half-tone cuts, and are indicated with an asterisk. It was not possible to insert cuts of all the important structures, but a sufficient number have been given to indicate the charactor of the buildings constructed from the stone.

Partial List of Buildings Constructed Out of Lake Superior Brownstone.

Name of building and date of construction.	City.	Part constructed out of stone.	Quarry.
Aberdeen Hotel	St. Paul		Washburn Co.
Adam's Flats	Duluth		Port Wing Co.
A. H. Wilder's flats	St. Paul		Washburn Co.
*Bayfield County Court House 1895	Washburn	Superstructure, substructure	Washburn Co.
Bank building. 1895	Winnipeg	Superstructure, substructure	Iron River Co.
Bank of Commerce Bldg. 1888	Minneapolis	Superstructure substructure	Washburn Co.
Banning block. 1871	Duluth		Duluth Co.
Bridges and culverts	C., St. P., M. & O. Ry		Washburn Co.
Bridges, 1896	Wis. Cen. Ry		Ashland Co.
Buffalo Flats	Duluth		Cranberry river
Catholic church. 1892	Superior	Superstructure, substructure	Arcadian Co.
*Central High School	Duluth	Superstructure, substructure	Flag River Co.
*Central High School	Duluth		Cranberry river, (in part).
Chamber of Com. Bank Bldg	Minneapolis		Washburn Co.
Chamber of Commerce. 1893-'94	Detroit	Superstructure, substructure	Excelsior Co.
Church of Redeemer. 1891	Superior	Superstructure, substructure	Arcadian Co.
City pumping station	Duluth		Port Wing Co.
Cincinnati City Hall. 1889-90	Cincinnati,	Superstructure, substructure	Prentice Co.
Clark & Hunter blocks 1870	Duluth		Duluth Co.
*C., St. P., M. & O. depot. 1897	Duluth	Superstructure, substructure.	Port Wing Co.
* C., St. P., M. & O depot. 1896	Eau Claire, Wis.		Ashland Co.
Dan. Head & Co's Bank	Kenosha		Arcadian Co.
Davis' Commission House	Duluth		Port Wing Co.
Elevator H.	Duluth	Foundation	Duluth Co.
Elsinder Flats. 1892.	St. Paul	Entire structure.	Iron River Co.
Ex-Mayor Pattison's residence. 1890	Superior	Foundation and basement	Arcadian Co.
Ex-Gov. Merriam's residence, 1887.	St. Paul	Superstructure, substructure	Washburn Co.
Fire Hall No. 1	Duluth		Duluth Co.
Flour mills	Superior	Substructure	Iron River Co.
Forepaugh Bldg	St. Paul		Washburn Co.
Fred C. Pillsbury's residence. 1889	Minneapolis		Washburn Co.
1st M. E. Church	Duluth		Bass Island Co.
1st National Bank	Duluth	All the stone work	Duluth Co.
German American Bank	St. Paul		Duluth Co.

Partial List of Buildings Constructed Out of Lake Superior Brownstone.— continued.

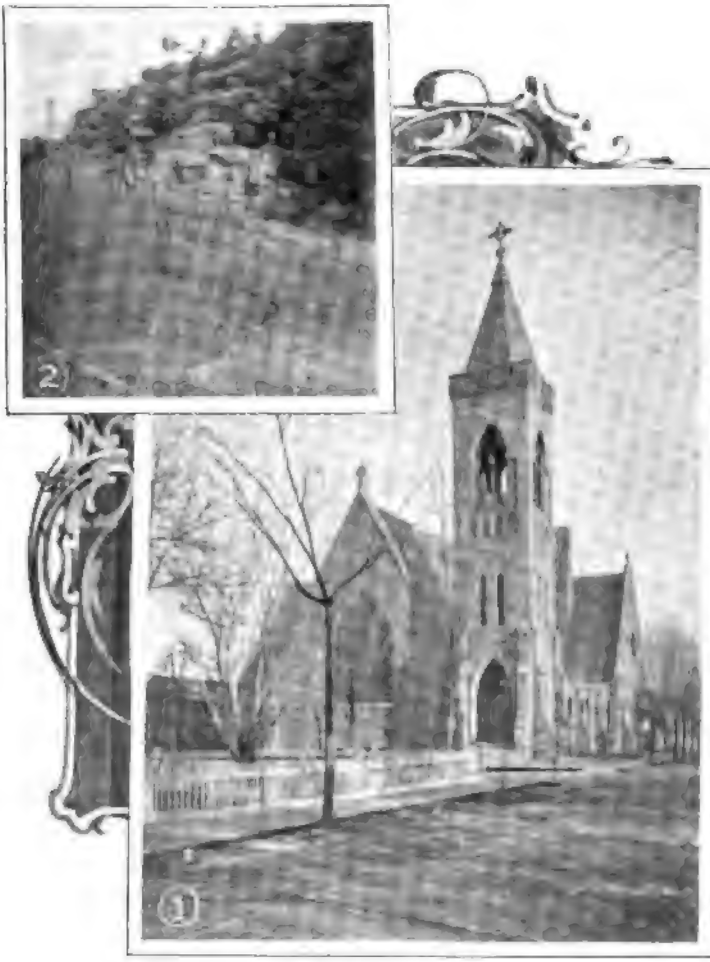
Name of building and date of construction.	City.	Part constructed out of stone.	Quarry.
Grand Hotel	Winnipeg		Port Wing Co.
High School	Minneapolis		Washburn Co.
High School	Racine	Basement and trimmings	Arcadian Co.
Holmberg Flats	Minneapolis		Port Wing Co.
Hudson Bldg. 1891	Detroit		Ashland Co.
H. P. Rugg's residence	St. Paul		Washburn Co.
Irwin School. 1894	Duluth	Superstructure, substructure	Port Wing Co.
Jefferson School. 1893	Duluth	1st story and basement and trimmings	Iron River Co.
Jno. Paul's residence	La Crosse		Bass Island Co.
Kelley's Commission House	Duluth		Port Wing Co.
Kenwood Flats	Minneapolis		Washburn Co.
Knight Block. 1890	Ashland	Superstructure, substructure	Ashland Co.
Library Bldg	Rochester		Washburn Co.
Library Bldg	Fairbault		Washburn Co.
Lockley Flats. 1893	St. Paul	Superstructure, substructure	Iron River Co.
L. P. Hunt's Business Block	Mankato		Washburn Co.
*Lumber Exchange	Minneapolis		Prentice Co. (in part)
*Lumber Exchange	Minneapolis		Washburn Co.
Lyceum Building	Duluth	Superstructure	Duluth Co.
Masonic Temple. 1895	Ashland		Excelsior Co.
Massachusetts Blocks	Duluth		Duluth.
M. E. Church. 1895	Duluth	All stone work	Iron River Co.
Metropolitan Opera House. 1895.	Minneapolis		Washburn Co.
*Milwaukee County and City Court House	Milwaukee	Superstructure, substructure	Washburn Co.
Northern State Bank	Washburn	Superstructure, substructure	Washburn Co.
Odd Fellows Hall. 1892	St. Paul	Superstructure, substructure	Iron River Co.
One of the buildings of University of Minn	Minneapolis	Superstructure, substructure	Iron River Co.
Park Cong. Church. 1895	St. Paul	Basement and trimmings	Iron River Co.
Pearl St. School House	Sioux City, Iowa		Washburn Co.
Phillip's Block	Sioux Falls, S. D.		Washburn Co.
Plankington Bank Bldg	Milwaukee		Bass Island Co.
*Post Office	Ashland	Superstructure, substructure	Prentice Co.
Potter Palmer's residence. 1889	Chicago	Superstructure, substructure	Prentice Co.
Preparatory College to University of Minn	Minneapolis		Washburn Co.

Partial List of Buildings Constructed Out of Lake Superior Brownstone.— continued.

Name of building and date of construction.	City.	Part constructed out of stone.	Quarry.
Providence Bldg. 1895	Duluth	1st story and basement	Iron River Co.
Public Library. 1887	Minneapolis		Washburn Co. (in part).
Public School Bldg.	Omaha		Washburn Co.
Railroad Hotel	Winnipeg	Superstructure, substructure	Flag River Co.
Ransome Flats. 1893	St. Paul	Substructure, trimmings, and 1st story	Iron River Co.
St. Louis county vault	Duluth		Port Wing Co.
St. Mary's Hospital. 1897	Duluth		Port Wing Co.
St. Paul Globe Bldg., 1886	St. Paul		Washburn Co.
St. Paul Dispatch Bldg. 1895	St. Paul	Superstructure, substructure	Bass Island Co.
St. Paul's Church	Milwaukee		Bass Island Co.
Schmidt Block. 1894	Detroit		Ashland Co.
School House	Duluth	Brownst'ne range and white stone trimmings	Duluth Co.
*Second Lumberman's Exchange	Minneapolis	Superstructure, substructure	Flag River Co.
Security Bank Building	Sioux City		Arcadian Co.
Several school-houses. 1894	Winnipeg	Basement and trimmings	Iron River Co.
State Asylum. 1897	Cherokee		Port Wing Co.
State Normal school. 1895	Superior	Foundation and trimmings	Arcadian Co.
Security Bank Bldg.	Sioux City, Iowa.		Washburn Co.
Telephone Bldg. 1891	Detroit		Ashland Co.
Temple Opera House	Duluth		Arcadian Co.
10th St. Church	Minneapolis		Washburn Co.
Tribune Office Bldg. 1871	Chicago		Bass Island Co.
23rd St. Church	Minneapolis		Washburn Co.
Union Block	Washburn	Superstructure, substructure	Washburn Co.
*Walker High School. 1895	Washburn	Superstructure, substructure	Washburn Co.
Walnut St. Opera House. 1892	Cincinnati	Superstructure, substructure	Prentice Co.
Washington High School	St. Paul		Duluth Co.
Wealin Block	Duluth		Duluth Co.
Westminster Pres. Church	Minneapolis		Duluth Co.
West Superior Hotel	West Superior		Duluth Co.
Wright Block. 1888	Minneapolis		Washburn Co.

The brownstone from the Prentice Brownstone Quarry has been used for constructional purposes in a total of 10 states and 40 cities, among which are the following:

New York — New York City, Brooklyn, Ogdensburgh, Rochester, Troy, Buffalo.
Ohio — Cleveland, Toledo, Sandusky, Cincinnati.
Michigan — Detroit, Port Huron, Lansing, Escanaba, Bay City, Jackson, Ann Arbor, Battle Creek.
Illinois — Chicago, Peoria, Rockford, Bloomington.
Wisconsin — Madison, Eau Claire, Ashland, Superior.
Minnesota — St. Paul, Minneapolis, Duluth, Austin.
Iowa — Des Moines, Sioux City, Council Bluffs.
Missouri — St. Louis, St. Joseph, Kansas City.
Nebraska — Omaha.



DUNNVILLE SANDSTONE.

1. Episcopal Church, Stevens Point, Wis. 2. A portion of the Dunnville Quarry.

CHAPTER IV.

SANDSTONE (continued).

SOUTHERN POTSDAM SANDSTONE.

The Southern Potsdam Sandstone is immediately adjacent to the great north-central crystalline area, bordering it on the south, east, and west. The sandstone of this area is supposed to have been laid down contemporaneously with the Lake Superior sandstone, although the latter contains no known fossil remains, and is not connected geographically with the former. The sandstone of the sounthern area is widely different at different horizons, as well as in different parts of the same horizon. It varies in color, texture, and composition, and the hardness, strength, durability, adaptability, and beauty, all vary accordingly. The surficial extent is very large. (See General Map, Pl. I.) The formation extends from the Menominee river in the northwestern part of the state around to the southern part, and thence northwest in a broad belt as far as the center of Burnett county. In spite of its large surficial extent, it may be said that this area, in general, supplies perhaps as small a percentage of good building stone as any treated in this report.

The sandstone is quarried and used locally throughout the entire region, but only in a few places is the stone exploited for shipment. In nearly every village and town located in the Potsdam sandstone region the stone is used for foundation purposes, while in some of the more favorable localities, it has been used in the construction of local buildings and bridges. In only two small areas has the stone been quarried extensively for

shipping purposes. One of these areas is known as the Dunnville, and the other as Ablemans. At a number of other localities, among which may be mentioned Madison, Mineral Point, Baraboo, Grand Rapids, and Stevens Point, the stone has been used quite extensively in the construction of local buildings.

In color, the stone varies from an almost pure white, through buff and brown, to a brilliant red. The stone usually contains a greater or less percentage of brown iron oxide, and consequently the predominant color is either buff or brown. The red sandstone occurs mainly in a region, as yet undeveloped, about four miles from LaValle on the C., St. P., M. & O. Ry. Almost pure white sandstone is obtained mainly from a single quarry at Ablemans. The brown and buff colored varieties are distributed very irregularly throughout the entire region, and often two or more shades of brown or yellow are taken from the same quarry.

The sandstone varies from a very coarse granular rock to one which is exceedingly fine grained. In certain places the rock is so firmly cemented by silica that it would almost pass for a quartzite. In other places the grains are scarcely cemented at all, and the stone is so friable that it crumbles in the hand. In other instances the rock is cemented with either calcium carbonate or iron oxide. In the former case the sandstone is generally fine grained and more firmly compacted than in the latter. The ease with which the stone can be cut and dressed depends mainly upon the degree to which it has been cemented, and the kind of cementing material. If a sandstone is poorly cemented, and very soft, it generally crumbles beneath the cutter's tool; and if it is very firmly cemented with silica, it is often exceedingly refractory and too expensive to cut and dress. In both of these extremes the stone is unsuited to economical working. If the stone is moderately well cemented with silica, or well cemented with iron oxide or calcium carbonate, it can generally be worked with much greater readiness and to much better advantage.

Wherever the Potsdam sandstone occurs it is generally easily accessible, and can be taken from the quarry in blocks of any

reasonable size. In places, the joints are perhaps more abundant than is desirable, but where the stone is unsuited for fine constructional work, the presence of numerous joints is frequently a decided advantage, rather than a hindrance.

Scarcely any of the quarries of this area are equipped with any but the simplest quarrying appliances. The ordinary outfit is a hand-drill, a crowbar, sledges, and a can of powder. In quarrying no attention is paid to the condition of the stone after it is taken from the ledge, the only object being to exploit it with the least possible expense.

As previously mentioned, the markets for the stone are almost entirely local. The Dunnville quarries furnish a limited amount of stone for constructional purposes to a number of cities within this and neighboring states. The stone that is quarried at Ablemans is sold mainly within the state, and is used very largely by the C. & N. W. Ry. for bridge construction.

The following pages are intended to give a more specific idea of the character of the stone as it is quarried at these and other localities within the region under discussion.

Description of Individual Areas.

DUNNVILLE AREA.

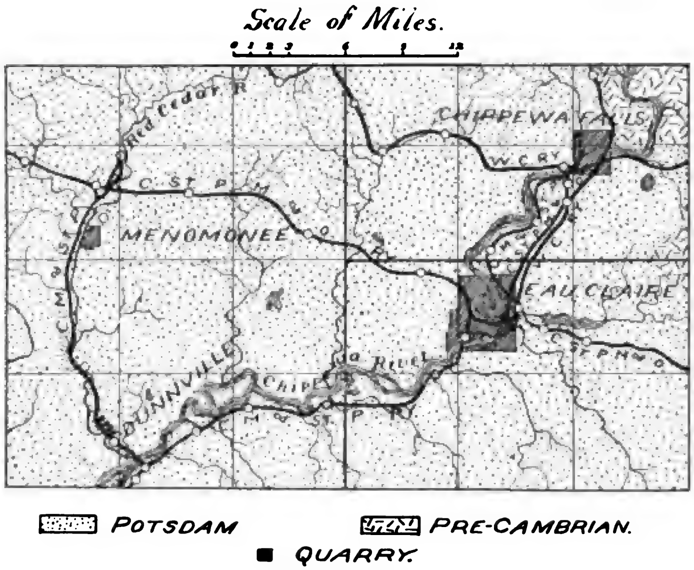
The Dunville quarries are located along the eastern escarpment of the Red Cedar river, being scattered along the railroad for a mile north of Dunnville station. The quarries are immediately adjacent to the C., M. & St. P. Ry., the stone being, in some cases, quarried from the right of way. For a distance of about a mile north of Dunnville, the railroad skirts the base of the escarpment, which presents an almost continuous vertical cliff from 10 to 40 feet high. At one time or another, stone has been quarried from nearly every part of the cliff, operations having been shifted from one place to another, to avoid heavy stripping and occasional rotten and ferruginous places in the ledge. At the present time, quarrying is being conducted at four places along the escarpment. The first quarry is about

one-third of a mile north of Dunnville station. Two others are a short distance north of this one, and the last is about a mile from the station.

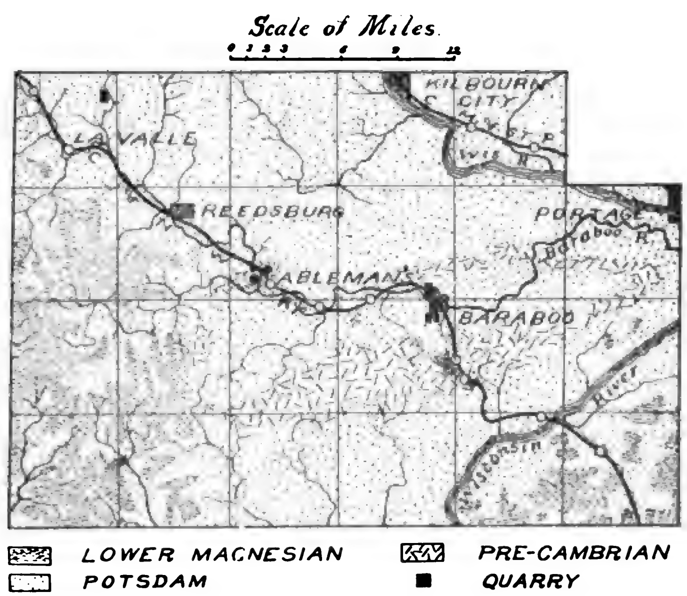
Quarry Observations.

All of the stone from those quarries is essentially the same, although there are local differences in color and texture. Plate XXXVII., shows the succession of beds as they occurred at the four different openings, at the time they were visited in the summer of 1897. It will be seen that each of the quarries consists of alternating beds of sandstone and shale. Certain of the beds are solid, while others are laminated and shaly. The beds vary in thickness from a fraction of an inch to 6 or 7 ft. They are not of constant thickness, but may be solid in one part of the quarry and break up into two or more beds in another part. A certain bed may furnish good dimension stone in one part, while that taken from another part of the same bed may be worthless. The heavy beds extend throughout the entire length of the escarpment and constitute the principal source of the building stone. When first quarried, the stone generally shows quite distinct stratification planes, but after seasoning the evidences of stratification largely disappear. Besides being distinctly bedded, the stone is also broken into irregular blocks by two sets of joints, striking in general about N. 80° W. and N. 8–10° E. These joints occur at irregular intervals, and are occasionally as much as 10 or 15 feet apart but, as a rule, they are much closer.

The color of the stone differs very little in the different beds, being in general a very light buff. In some of the uppermost beds it is more of a gray or bluish white. The texture of the stone from all the quarries is not the same, being very fine grained in some and much coarser in others. When first quarried, the stone cuts very easily, being susceptible to the finest kind of carved work. Under ordinary conditions, the stone will be seasoned after one or two weeks drying. It then works less readily under the chisel. When taken from the quarry, the



DUNNVILLE AREA.



BARABOO AREA.

stone is apparently almost completely saturated with water. At many places along the escarpment the water drips or runs out from between the different ledges of rock, indicating that the water content is very large, and that it is readily given up.

Laboratory Examination.

The Dressed Sample.—The stone from these quarries has a very pleasing buff color. The sample which is in the laboratory of the Survey shows very excellent rock, ribbed, bush hammered, and sawed faces.

Microscopical Examination.—An examination of the thin section of the rock under the microscope shows that it is very fine grained. (See Plate LXVII., Fig. 1.) It consists mainly of fine angular grains of quartz, mingled with which are lesser amounts of feldspar, muscovite, and biotite. The interspaces between the grains are small and numerous, but are supposed to be of capillary size. The exceeding fineness of the grains gives little chance to determine the amount or kind of cementing material which binds them together, but in the process of grinding, many of the grains were pulled apart, indicating a rather loose cementation.

Physical Tests.—The specific gravity of the rock, as shown in Chapter VIII., Table V., is 2.59, which is somewhat lower than that of the Lake Superior brownstone. The percentage of water absorbed by the stone is very high, being 15.17 per cent. The actual porosity averaged 28.28 per cent Due to freezing and thawing, the samples lost in weight an average of .16 of a gram, on a mass of about 234 grams. (See Chapter VIII., Table VI.) The effect of alternate freezing and thawing on the crushing strength is given in table VII., in which the crushing strength of the frozen samples averages 742 lbs. per sq. in. more than that of the fresh samples. This does not indicate that the stone is stronger on account of having been frozen, but that the frozen samples were more carefully prepared than the others, and that the alternate freezing and thawing had little or no effect upon the strength. When subjected to an extremely high

temperature, the Dunnville sandstone changed to a yellowish brown color. At 1,000° F. the samples were apparently little affected, but when heated to 1,200° F. cracks were developed across the samples and the strength was nearly gone. The samples could be broken with the fingers.

The maximum crushing strength of the stone was about 3,000 lbs. per sq. inch. (See Chapter VIII., Table II.) It will be noticed that the strength is somewhat lower than that obtained for other sandstones, yet it is sufficiently high to insure perfect safety when used in buildings of moderate size.

General Considerations.

In general, the Dunnville sandstone, if properly quarried, will serve as a valuable material for light constructional work. The ease with which it carves makes it especially well adapted for uses where great strength is not required. The excellence of carving and beauty of the stone are well shown in the Mabel Tainter Memorial Hall, Menominee, Wis., illustrated in Plate XXXVIII.

The quarries are all very scantily equipped with machinery. Steam power has not yet been used, either in quarrying or cutting the stone. Blasting and wedging are the methods employed in quarrying. Drilling is done by hand, and the derricks are manipulated either by hand or horse power. Through blasting, much good stone has been destroyed, while all the stone thus quarried is more or less injured. The larger pieces are also broken with heavy hammers, a method which is very injurious to the life of the stone. Under present conditions, the better method would be to use steam drills and wedges.

The stone has been used quite extensively for brick trimmings, and a number of moderate sized buildings, in the west central part of the state, have been entirely constructed out of stone from these quarries. It has been used quite largely in St. Paul, and has found its way as far south as Madison, where it has been used for trimming Hiram Smith Hall of the University. The finest building in the state constructed out of Dunn-

ville stone is the Mabel Tainter Memorial Hall at Menominee, Dunn County. (See Plate XXXVIII.) The St. Paul's church at Stevens Point is another pretty building, also constructed out of Dunnville sandstone. (See Plate XXXV.)

Description of Individual Quarries.

DUNVILLE QUARRY.

Operations were begun at the Dunnville quarry in 1884, by Wm. H. Ulmer, and the quarry has been operated each year since. The quarry with 44 acres surrounding the opening, is owned by S. A. Ulmer of St. Paul. This quarry is about a mile north of the Dunnville station. A small portion is shown in Plate XXXV.

The face of the quarry is about 525 ft. long and trends approximately north and south. The face is about 25 ft. deep, and has been worked back about 50 ft. The succession of beds is shown in Plate XXXVII.

The best stone is obtained from the lowest beds, which, at the south end, are respectively 6, 1½, and 4 ft. thick. Farther north, along the face, the character of the rock changes, the best stone being quarried mainly from the lowest ledge of 6 ft. In certain parts of the quarry, the stone in this ledge is rotten and irregularly stained with iron oxide, occasioning a considerable expense for removal. Above the lower heavy ledges the stone is thinly bedded and interlaminated with clay layers. These upper beds often contain numerous fossils, and are classed mainly as rubble and stripping. The best stone from these beds is sold for rough foundation work, but it has not yet paid for removal.

The samples used in testing the Dunnville sandstone, the results of which are recorded in the tables in Chapter VIII., were furnished by Mr. Ulmer, from this quarry, and they represent fairly the stone from the entire area.

The stone from this quarry is sawed at the company's yard in St. Paul, and has been furnished for buildings, foundations, and bridges. It is graded and sold as rubble and building stone, and

may be obtained in any size that can be handled by the derricks. The output from this quarry was 100 cars in 1892, and 300 cars in 1896, indicating an increasing demand for the stone.

The main buildings, in the construction of which the stone from this quarry has been used, are the City Hospital, St. Paul, Minn., Mabel Tainter Memorial Hall, Menominee, Wis., and the Home for the Feeble Minded, Chippewa Falls, Wis.

Statistical Data of the Dunnville Quarry.

Amount of capital invested: $5,000.00.

Facilities at hand for quarrying: 4 gang saws, 3 horse power derricks.

Average number of employees: 7.

Wages paid different classes of employees: $1.50 to $2.00.

Cost of cutting and dressing stone per cubic foot: $.50.

Average value of each grade per cubic foot: Mill blocks, $.15; rubble, $.02.

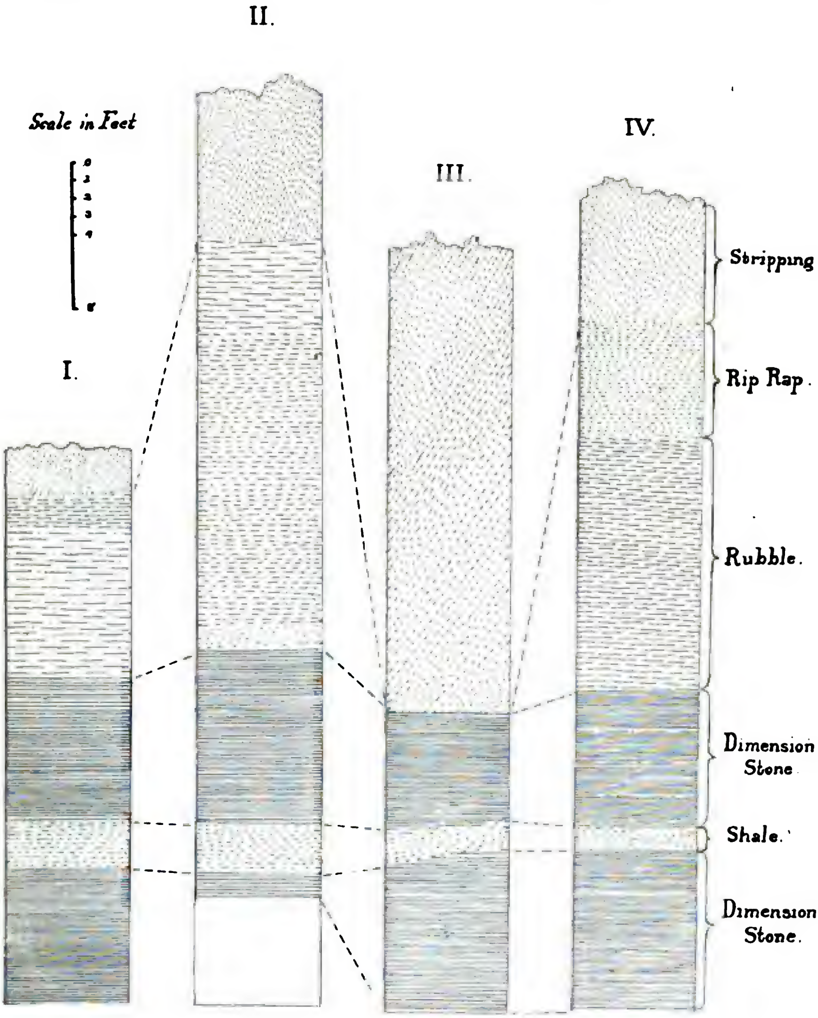
Shipments for the past five years:

1892	100 cars
1893	150 cars.
1894	150 cars.
1895	200 cars.
1896	300 cars.

LANG'S QUARRY.

The second quarry of this area, owned and operated by Robert A. Lang, is a short distance south of the Ulmer quarry. The stripping at this place is from 6 to 12 ft. deep, and owing to the steepness of the bluff, in the rear of the escarpment, may increase considerably as the quarry is worked back. The succession of beds is given in Plate XXXVII. The three lower ledges, 4½ ft., 6½ ft., and 8 ft. thick, with the exception of about 3 ft., are quarried for dimension stone. The remaining 16 ft. above are used for rubble. The beds are thin, interlaminated with clay, and contain iron segregations. Much of the stone from the upper beds is unfit for any use, and should be removed from the quarry as stripping or dump.

When first taken from the quarry, the stone from the massive beds is wet, and shows a black streaky lamination, which disappears after the stone has been seasoned.



VERTICAL SECTIONS OF THE DUNNVILLE QUARRIES.

1. Ulmer's Quarry.
2. Lang's Quarry.
3. Lester's Quarry.
4. Celleyham's Quarry.

The quarry is worked by blasting and wedging. A hand derrick is used in loading the stone from the quarry to the cars. No statistical data could be obtained relative to the operation of this or the following described quarries.

LESTER'S QUARRY.

The quarry owned and operated by Wm. Lester is located a short distance south of Lang's quarry, and has a face which extends along the escarpment about 150 feet. The stripping of clay and gravel is from 4 to 30 feet deep, averaging about 20 feet. Beyond the cliff the hill rises quite abruptly, making the quarrying in that direction somewhat uncertain. The rock escarpment at this point is only 13 ft. deep, and consists of two beds, separated by a thin shaly layer. The two exposed ledges are each, on an average, 6 ft. thick, while the intermediate bed of shaly material has a thickness of one foot. (See Plate XXXVII.)

The upper 3 ft. of the topmost bed are much broken up, and the stone is classed as rubble. All the No. 1 dimension stone is quarried either from the remainder of this or from the lowest bed.

The heavy stripping almost precludes the possibility of working this quarry to advantage. Hydraulic means might be employed to remove the soil, but it is not certain that the expense of this method would not be too great to make quarrying profitable. Part of the stone used in the Mabel Tainter Memorial Hall was quarried at this place.

CELLEYHAM'S QUARRY.

The quarry operated by Grant Celleyham is located on the property of the C., M. & St. P. Ry., known as the "Right of Way." The soil covering is from 5 to 6 ft. deep, and the indications are that it will not increase for some distance back from the face. The succession of beds, as illustrated in Plate XXXVII., shows the condition of the quarry better than it can be described. The best stone is quarried from the lowest bed

of 7 ft. and the second one above having a thickness of from 6–8 ft. This last bed splits, in some places, into four or five smaller beds. The stone in this bed is harder than that of the lowest bed, and is in places somewhat discolored. The next 10 ft., above, are mainly rubble, and the stone is used for foundations. The uppermost beds, having a thickness of five feet, are rip-rap, and come under the head of stripping. The quality of the stone does not differ essentially from that of either of the other quarries.

The Dunville stone carves beautifully, and will remain permanent a long time. The porosity is high, but this factor has little significance when we consider the size of the pores, which are sufficiently large to place the stone out of danger from frost under ordinary conditions. The stone should be laid on the bed, and care should be taken not to shatter the stone by use of heavy tools in dressing or quarrying.

The buildings, in the construction of which the Dunnville sandstone has been used, thus far show no deterioration. The color is very pleasing, and no stone takes a better rock face finish, or is cut and carved with better effect. The future of the industry at this place depends upon a number of factors, the principal of which is the facility with which the stone can be quarried. There is certainly an abundance of stone, but the heavy stripping, the accumulation of rip-rap, and the crude methods of quarrying are hindrances to successful operation.

BARABOO AREA.

In the Baraboo area quarries have been opened in both the Potsdam sandstone and the pre-Cambrian quartzite. The quarries in the Potsdam of this area furnish some of the strongest and most durable sandstone quarried in the state. The stone which is quarried for shipping is obtained mainly at Ablemans. Other quarries are located in the vicinity of Baraboo and LaValle. The sandstone in the different quarries differs greatly in color. That which is quarried at Ablemans is either white or yellowish brown, while that from LaValle is a brilliant red.

The quarries of Ablemans are located on outliers of the Potsdam sandstone, in and about the Baraboo quartzite bluffs. The quarries at Baraboo and LaValle are situated in the main Potsdam area.

Since the stone and the uses to which it is put are essentially different in each of these places, they will be considered separately.

Quarries at Ablemans.

The quarries at Ablemans are located immediately adjacent to the C. & N. W. Ry., and in close proximity to the quartzite outcrops of the Baraboo bluffs. (See Plate XXXVI.) The quarries are owned and operated by three different parties, the C. & N. W. Ry. Co., Wm. Gall, and Ernest Tultz. The operations of the first mentioned are the most extensive. The color of the sandstone is either pure white or a yellowish brown. It is often very hard, being in some places quite similar to quartzite. In other places it is less firmly cemented, and consequently much more friable. On account of its refractory nature, the rock is often difficult to dress, but when finished the surface has a very pleasing effect. The rock is medium to coarse grained.

Laboratory Examination.

Microscopical Examination.—The microscopical examination of the rock shows that it is composed of roundish grains of quartz, which have been occasionally enlarged by secondary growths and cemented with silica. The grains are generally of uniform size and fairly well rounded, as shown in Plate LXVII., Fig. 2.

Chemical Analysis.—The chemical analysis of the white sandstone, as made by Prof. W. W. Daniells, is given in the following table. In one hundred parts by weight, the rock contains:

$Si\ O$	98.64
Al_2O_3 } Fe_2O_3 }	1.10
	99.74

This analysis shows that the rock is composed essentially of silica, there being only 1.10 per cent. of other constituents.

Physical Tests.—The physical tests which were made upon samples from the C. & N. W. Ry. Co.'s quarries show that the stone is eminently suited for heavy constructional work.

The crushing strength averages over 10,000 lbs. per sq. inch, which is higher than that of any other sandstone from Wisconsin, that was tested in the preparation of this report. The modulus of rupture, which ranges from 845–1324 lbs. per sq. in., indicates that the stone is also well suited for caps and sills. The specific gravity and porosity of the rock are given in Chapter VIII., Table V. The average specific gravity is 2.574, while the average percentage of water absorbed is 2.63 per cent. The average porosity is 7.12 per cent., which is exceptionally low for a medium grained sandstone. A sample of the sandstone, subjected to extreme heat, was not injured at a temperature of 1,000° F. At a temperature of 1,200° F., the sample gave some evidence of cracking, and when cooled it had the peculiar ring characteristic of brick. The strength was mostly gone. Samples of the stone were not received in time to test for the effects of alternate freezing and thawing, but it is evident from the medium size of the pores and the low porosity, that the stone will not be materially injured by alternate freezing and thawing, under ordinary conditions.

General Considerations.

The results of the laboratory tests show that the stone is admirably suited to the purposes for which it is being used, mainly heavy constructional work in the shape of bridges, arches, and foundations.

The stone, as it occurs in the quarries, gives no indication of bedding, being essentially solid throughout the quarry. The jointing is different in each of the quarries, but is generally not so close but that blocks of almost any dimension can be taken from the different ledges. The stone should be laid on the bed, although the apparent absence of bedding places makes this less

DUNNVILLE SANDSTONE.

Mabel Tainter Memorial Hall. Menomonie, Wis.

imperative than in other sandstones. The absence of bedding planes makes the stone especially desirable for work near what is known as the water line, where the freezing of the water often breaks the stone into thin laminae.

C. & N. W. RY. CO.'S QUARRY.

The C. & N. W. Ry. Co. have made three openings about half a mile north of the station. It is from only one of these openings that white sandstone is quarried. In this opening the stone is only occasionally discolored by streaks of iron oxide. The quarry face at this place is about 50 ft. high, with a length of about 200 ft. The stone is essentially massive, bedding planes being made out only after the most careful scrutiny. The stratification planes are so faint that quarrymen cannot make use of them in their work.

The cost of cutting and dressing the stone is about the same as that required for cutting and dressing granite, but on account of its freedom from impurities and essentially uniform texture, it will probably prove more durable than granite. For this reason it is to be preferred to many of the igneous rocks. The company uses the stone from this opening for its best and heaviest masonry work.

The second opening is immediately south of the one just described. The color of the stone quarried from this opening varies from a reddish brown to a light pinkish brown, being sometimes streaked brown and white. The major part of the stone has a uniformly light brown color. Near the surface, the stone is very much fractured by two sets of joints, one of which strikes N. 55° E. The other set strikes diagonally across the first at very irregular intervals, and in uncertain directions. These jointing planes break the stone into blocks, which frequently attain a size of 6 ft. by 2½ ft. by 3 or 4 ft. Where the jointing is much closer, the blocks are of correspondingly smaller size. The stone has no rift, and splits in a very irregular and uncertain manner, often making it difficult to work the quarry to advantage. The stone dresses fairly well, but is not as strong

or as well indurated as that which is quarried from the previous opening. It works more readily, and is less expensive than the white sandstone; but is almost equally as good for bridge work.

A third opening has been made a short distance east of the last, to which a short railroad spur has been run from the main track. The stone is very similar to that which is quarried from the last described opening, but has a somewhat lighter color and the joints are less abundant.

The company has lately employed as many as 100 men at the different openings. The stone is too hard for ordinary channeling, and cannot be satisfactorily worked by wedging. For these reasons, it is extracted mainly by blasting. The stone is so well cemented that it is injured very little when light charges are used in moving the blocks. Steam drills and steam derricks are used in the quarry.

This stone is now being used almost exclusively for bridge abutments, culverts, arches, retaining walls, and rip-rap work along the line of the C. & N. W. Ry. The stone has also been used for bridge work in Chicago, where it is considered one of the best stones obtainable for this purpose. The difficulty in working the stone is compensated for by its durability and strength, which are far above those of the average stone. There is probably no stone quarried which is more suitable for railroad work, or which will last a greater number of years, than that which is quarried by the C. & N. W. Ry. Co. at this locality.

GALL'S QUARRY.

Gall's quarry is located immediately west of the Baraboo river, almost opposite the quarries of the C. & N. W. Ry. The stone is taken from a single opening, and has either a light or dark reddish brown color. The lower beds in the quarry are almost white, but somewhat streaked. The stone is bedded and much more easily quarried than the stone worked by the C. & N. W. Ry. Co. It is also softer and much more easily dressed.

The face of the quarry is from 50 to 60 ft. high, without any apparent floor. The stone is quarried from the top to the bot-

tom of the ledge, and no attempt is made to work back into the hill. The joints strike N. 55° E. and N. 30° W. The first set is the more important, and the direction varies least. The second set is very irregular, and the strike varies considerably in direction. The stone from this quarry has been used very largely for foundation purposes, but is not quarried to any extent for building. The quarrying is done mainly by drilling and wedging. The stone is moved with hand derricks, and the drilling is mainly done by hand. In these days when steam is so universally used to furnish power for quarrying, the man who uses muscle instead, is placed at a great disadvantage.

TULTZ'S QUARRY.

The quarry operated by August Tultz is located a short distance west of Ablemans. The stone from this quarry is essentially the same as that from the quarries just described. It has been used mainly for monument bases, although some stone has also been used for building foundations.

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In general, the sandstone from this locality is suited for bridge abutments, piers, foundation work, and other heavy constructional purposes. The stone is not easily worked, and is dressed only with some difficulty, for which reason it is more costly than the sandstone from other quarries in this state. It is very probable that the stone will never be used extensively, except for the purposes for which it is now being used by the C. & N. W. Ry. Co. For these purposes the stone ought to have a large demand, because no sandstone is quarried in this state which combines better the two qualities of strength and durability.

Quarries at Baraboo.

The Baraboo quarries have been operated almost exclusively for local purposes. The stone differs locally in color and hardness, but in most of the quarries has a yellowish brown or buff color. In certain places the stone is thoroughly indurated and almost as refractory as quartzite, while in others, closely adjacent, it is soft and friable. Whether the stone is soft or thoroughly indurated depends very largely upon the amount of

siliceous cement, which has been deposited in the interstices of the rock.

The two principal quarries are located a little southwest of the limits of the city of Baraboo, on the SW. ¼ of Sec. 2, T. 11 N., R. 6 E. The stone is of medium hardness and can be cut and dressed with comparative ease. The main quarry is on the land owned by the Levi Crouch estate, and on the land immediately adjacent is the quarry owned by Smith Jennings. The color of the stone is nearly white, with a tinge of yellow. These quarries furnish most of the stone used in the foundations for residences and business places in the city of Baraboo. The Warner Hotel and several other buildings have been constructed out of the sandstone from Crouch's quarry.

The supply of stone at this place is almost unlimited. The stripping is light, not exceeding 6 ft. The quarry has well developed joints, which are sufficiently far apart to permit the quarrying of large dimension blocks. The beds are very heavy, and, for this reason, some difficulty might be experienced in working the ledge for cheap stone. The stone has been quarried mainly by the use of powder or dynamite, by which method much stone has been shattered and destroyed.

An abundance of sandstone, similar in texture and color to that which is quarried adjacent to Baraboo, occurs about five miles northeast of the city. Small openings have been made, and the stone quarried for local consumption. The great difficulty in this locality is to obtain sandstone which is moderately hard. It must not be so refractory that dressing will be expensive, nor so soft that it will crumble under the chisel. A sandstone of medium texture and of medium hardness is best adapted to economical working.

In general, there is an abundance of sandstone in the vicinity of Baraboo, which is satisfactory for all local purposes, being far better than that which is often used in larger cities. Were it not for the refractory nature of much of the sandstone of this locality, it might be profitably quarried for shipment to other cities.

QUARRY AT LA VALLE.

Four miles north of the village of LaValle, in Sauk county, is a quarry of red sandstone owned by E. A. Grover. The quarry has not yet been developed, but a small amount of stone has been taken out for the purpose of obtaining fresh samples of the rock. The stone has a brilliant red color, but is often variegated with streaks of white.

The quarry is located on a somewhat abrupt escarpment, formed by a small creek which flows through the valley. It is difficult to estimate the amount of uniformly red stone which can be obtained at this place, but apparently it follows along the bluff for a considerable distance.

The dimensions which it is possible to obtain are sufficiently large for ordinary building or bridge construction. The stone was examined in the laboratory of the Survey, and thoroughly tested to determine its composition, strength, and durability.

Laboratory Examination.

Microscopical Examination.—The microscopical examination of the thin section shows the stone to consist of beautifully rounded grains of quartz, which have been secondarily enlarged, as suggested by the glittering faces of the particles in the hand specimen, as they reflect the rays of sunlight. The texture is somewhat finer than that of the Lake Superior brownstone but the individuals are apparently well cemented with silica. The brilliant red coloring is occasioned by the presence of an abundance of red iron oxide, which is irregularly distributed through the rock, coating many of the grains. (See Plate LXVI., Fig. 1.)

Physical Tests.—Two inch cubes, which were crushed in the testing machine, gave a crushing strength of 13,350 lbs. per sq. inch, and 11,460 lbs. per sq. inch, respectively. (See Chapter VIII., Table II.) The modulus of rupture of the sample tested was 362.9 lbs. per sq. inch, considerably below the average for sandstone. The specific gravity of the rock, given in Table V., is 2.643. The average ratio of absorption is 4.6%, while the

porosity is 10.81%. Table VI. shows that the loss in weight, due to alternate freezing and thawing, was scarcely anything on masses of 150 and 130 grams, respectively. The difference in the strength of the fresh and frozen samples, as indicated in Table VII., must be partially at least accounted for by irregularities in the shape of the cubes tested.

Samples subjected to high temperatures were but little affected at 800° F. At 1000° F. the color was changed almost to black, and the strength was essentially gone. At 1100° F. the sandstone was destroyed. The samples did not crack, but after cooling they crumbled into sand when pressed between the fingers. (See Plate LVII.)

These laboratory tests are sufficient to indicate that the stone is suited to a variety of constructional uses. For buildings, foundations, bridge abutments, culvert work, and retaining walls the stone can be used to good advantage.

Miscellaneous Areas.

Throughout the entire Potsdam sandstone region, wherever there is no other available rock, small quarries have been opened in this formation to furnish stone for local demands. Among the quarries which have been inspected in this region, the following is a nearly complete list:

Neillsville—D. B. Means, Peter Marks, Wm. Lapp, and Hemp and Hrachy.

Stevens Point—Patrick Connor.

Grand Rapids—Mrs. Henry Osterman, Fred Gailer, Wm. Yetter.

Centralia—John Collier, C. A. Bender, John Lindahl.

New London—Albert G. Westphal, Frank Monskey, August Paul, Wm. McDonald.

Black River Falls—E. L. Brockway.

Alma Center—Almond Cray, Mr. Wheeler.

Durand—John Poeschl, P. E. Hardy.

Sparta—Mr. Pope.

Portland—John McCormack, George Yergus.

Goodyear—Saddle Mound Sandstone Co., Mr. Levi P. Withee, La Crosse, President.

NEILLSVILLE AREA.

The sandstone in the vicinity of Neillsville has been used only for foundation purposes, most of it being taken from the large blocks near the base of the bluffs known as the Mounds. The bluffs are two or three miles northwest of the city, and rise to a height of about 100 feet above the level of the country. The sandstone in this vicinity shows two quite conspicuous sets of joints, which strike about N. 10° to 25° E., and N. 55° W.

Where exposed at the surface to weathering action, the rock is almost as hard as quartzite, and is covered with a thick growth of lichens. When the crust, which generally forms on the surface, is broken, the sandstone beneath has a decided tendency to crumble. This crumbling is characteristic of much of the sandstone, and makes it difficult to dress. The color is mainly white, but it is often streaked with red and brown iron oxide. There is an abundance of this sandstone, easily accessible, in this vicinity, but it is suited only to the roughest kind of foundation work. The stone is mostly quarried by D. B. Means, Peter Marks, and Wm. Lapp, each of whom own quarries in this vicinity.

In the town of Pine Valley, three miles from Neillsville, is located a quarry owned by Fred Hemp and Ferd. Hrachy. This quarry was opened in 1880, and has been operated each year since. The opening from which the stone is taken is of considerable size, and is surrounded by 200 acres of land owned by the company. The stone has been supplied mainly for building, foundation, and pier construction.

STEVENS POINT AREA.

The only quarry examined at Stevens Point is the one owned by Pat Connor. This quarry is located just west of the Wisconsin river on the outskirts of the city. The quarry consists of

two openings, the first of which is about 110 ft. long, 90 ft. wide and 25 ft. deep. The second opening is very irregular in shape, but is considerably larger than the first, having a back wall of about 700 ft. The first opening has been abandoned for some time, on account of the heavy stripping, which is about 12 feet thick.

The rock is distinctly bedded, the layers being from 1 to 2½ ft. in thickness. The stone becomes very hard upon exposure, and, as a rule, does not dress well, on account of its crumbly nature. The second opening shows three feet of soil and broken stone at the top, which is classed as stripping. Below this occurs 5 ft. of hard white sandstone, which has been used mainly for the finer class of work. This layer of stone is hard, and is the only one in the quarry which can be successfully cut and dressed.

The jointing planes are discolored with iron oxide, which has filtered along the cracks, and when the stone is not dressed before being placed in the buildings a bad effect is produced. By careful dressing and laying the surfaces which are discolored might be concealed within the wall.

Below this bed occurs 5 ft. 3 in. of shaly material, which is classed as stripping. Below this there are 17 ft. 8 in. of heavily bedded sandstone. In places the stone has an almost blue color, which is characteristic of sandstone firmly cemented with silica. The stone is difficult to cut on account of either its incoherent or refractory nature. From the heavier beds in the quarry, stone can be easily gotten out in blocks from 8 in. to 2 ft. in thickness. The major joints strike almost north and south, varying not more than 10° east or west. The second set strikes N. 40° E.

The stone from this quarry has been used in the construction of the Court House, and in the walls of several of the business blocks at Stevens Point. The stone is durable, and will last for centuries, but the difficulty experienced in cutting and dressing it, combined with its rough appearance in the wall, make it undesirable where beauty is one of the considerations.

The stone in this locality is excellent for rough foundation or

footing purposes, and ought to supply the local market with stone for all but the finer constructional work.

GRAND RAPIDS AND CENTRALIA AREA.

The quarries in the vicinity of Grand Rapids and Centralia are all in the Potsdam sandstone, which is the underlying rock of most of the surrounding country. There are six quarries in this vicinity, some of which were opened as early as 1865. Others were not opened until 1884 and 1887. The same diversity of texture and hardness prevails in this area, as elsewhere in the Potsdam sandstone. The stone from certain of the quarries is so thoroughly indurated that it resembles a quartzite, while the stone from other quarries is soft and friable and unsuitable for any kind of constructional work. As a rule, the stone is yellowish or buff colored, but in some instances it is almost white. The sandstone is medium to coarse grained, and is ordinarily cemented with silica. It is quarried entirely to supply local demands.

Some of the quarries are worked only during the winter months, others during the fall, while others are worked during the entire year. The facilities for quarrying are of the simplest kind, blasting and wedging being the methods used in extracting the stone. Hand derricks are occasionally used in hoisting the stone from the quarry to the wagons, but outside of this the quarries are very meagerly equipped.

Laboratory Examination.

Physical Tests.—Samples of the stone taken from the quarry, owned by C. A. Bender, of Centralia, were tested to determine the physical characteristics of the rock. The average specific gravity of the stone was determined to be 2.625. The ratio of absorption is 6.57%, and the porosity is 14.83%, which is less than that absorbed by the Lake Superior brownstone. Cubes of the sandstone were subjected to alternate freezing and thawing, with the results given in Chapter VIII., Tables VI. and VII. The loss in weight was about .05 of a gram on a mass of

over 275 grams, which is a practically inappreciable amount, when possible errors in manipulation are taken into consideration. The average crushing strength of the rock, after having been subjected to alternate freezing and thawing, was 8,233 lbs. per sq. inch, which is above the average compressive strength of coarse grained sandstone.

General Considerations.

As far as strength and durability are concerned, the best stone taken from these quarries is perfectly satisfactory for constructional purposes. The main objection to the stone, as has been previously noted, is the difficulty experienced in cutting and dressing. Unless the cementing material is of intermediate character, the stone will either be too refractory for easy working, or so soft that it crumbles under the chisel.

Description of Individual Quarries.

A very considerable amount of stone has been taken from the different quarries in this vicinity, some idea of which may be obtained from the descriptions of the various openings.

LINDAHL'S QUARRY.

The quarry owned and operated by John Lindahl, located about five miles north of Centralia, is of irregular shape, about 195 ft. long, 195 ft. wide, and 23 ft. deep. Most of the stone is thinly bedded, the different layers ranging from 2 inches at the top to 1 ft. 4 in. in the lower parts of the quarry. The stone is broken by two prominent sets of joints, striking N. 50° E. and N. 25° W. It has a brown to brownish white color, and has been used mainly for basements, buildings, stepping blocks, and hitching posts.

BENDER'S QUARRY.

The quarry owned and operated by C. A. Bender is located about a mile and a half west of Centralia. The quarry consists of two openings, the larger of which is about 180 ft. long, 100 ft. wide, and 15 ft. deep. The stone is medium grained,

and has a yellowish color. In some parts of the quarry it is very soft, while in others it is comparatively hard. The quarry is intersected by joints which strike N. 25° W. and N. 50° E. The upper 10 ft. in the quarry are very much broken up and the stone is classed mainly as stripping. The lower 14½ ft. are composed of quite massive beds, ranging from 3 to 4½ ft. in thickness. Blocks, 10 ft. by 2 ft. by 1 ft., are quite easily obtainable, and are generally uniform in color and free from imperfections. The stone from this quarry was tested in the Survey laboratory, and the results will be found in the tables in Chapter VIII.

Several small buildings have been constructed out of stone from this quarry, but the brown discoloration, occurring on the face of occasional blocks in the wall, mars somewhat the otherwise pleasing appearance of the building. Among the local buildings into which the stone has gone are the Grand Rapids Furniture Factory, the Oberbeck Furniture Factory of Centralia, the Centralia House of Grand Rapids, the Daly brick block of Centralia, and the Unity church of Centralia. Small dimension blocks have been used in the construction of these buildings, and it is thought that the appearance would have been much better had the blocks been of a larger size. The quarry is prepared to furnish stone for basements, piers, hitching posts, and all kinds of building purposes.

Statistical Data.

Amount of capital invested in equipment: $100.00.
Facilities at hand for quarrying: Drills, wedges, hammers, and bars.
Average number of employees: From 2 to 6.
Wages paid different classes of employees: $1.00 to $1.50.

OSTERMAN'S QUARRY.

The quarry owned by Mrs. Henry Osterman of Centralia, and operated by Henry Eberhardt, is located about 5 miles east of the city. The opening is about 250 ft. long, 100 ft. wide, and 2 ft. deep. The stone is much broken up by joints which strike N. 65° W. and N. 35° E. To all appearances, the stone can be

gotten out only in thin blocks of small size. The stone has been used in the Howe High School, the Court House, and Grand Army Hall of Grand Rapids.

Statistical Data.

Amount of capital invested: $200.00.
Average number of employees: Two.
Wages paid different classes of employees: $1.50.

YETTER'S QUARRY.

The quarry owned and operated by Wm. C. Yetter is located about 5 miles east of Grand Rapids. This quarry consists of two openings, one of which is about 200 ft. long, 50 ft. wide, and 30 ft. deep. The second opening is 30 ft. long, 20 ft. wide, and 10 ft. deep. The stone has the same general characteristics as the previously described quarries, and is used for buildings, piers, and paving.

Statistical Data.

Amount of capital invested: $1,500.00.
Facilities at hand for quarrying: 1 hand derrick.
Average value per cubic foot: Building, $.02; paving, $.05.
Shipments for the past two years: 1894, 110 cds. 1896, 150 cds.

COLLIER'S QUARRY.

Another small quarry in this vicinity, owned by John Collier of Centralia, furnishes stone which does not differ essentially from that of the other quarries.

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In general, the sandstone of this area is suited mainly for foundations, culverts, piers, monument bases, hitching posts, and similar uses. The stone is practically unlimited in quantity, but will probably never be used for anything but local consumption.

NEW LONDON AREA.

The stone quarried in the vicinity of New London is taken mainly from the upper beds of the Potsdam sandstone and the

lower beds of the Lower Magnesian limestone. The quarries, from which stone is exploited to meet the local demands, are operated by Albert G. Westphal, Frank Monskey, August Paul, and Wm. McDonald. The stone is used mainly for foundation purposes. It has a yellowish color, and shows the same variations in texture as the sandstone from other localities. The quarries are about four miles east of the city.

BLACK RIVER FALLS AREA.

The Potsdam sandstone which outcrops close to the city of Black River Falls is used mainly for foundation purposes. The quarry is on the east side of the river, and is owned by E. L. Brockway. The stone has a yellowish white color. The jointing is very irregular, and the beds are thin. The sandstone in this vicinity is less suitable for foundation purposes than the granite and other igneous rocks which are found in abundance along the river.

ALMA CENTER AREA.

The sandstone quarried near Alma Center is very similar to that which occurs at Black River Falls. It is quarried from the upper beds of the Potsdam series, which cap the bluffs about three miles south of the city. The stone, which is quarried by Almond Cray and Mr. Wheeler, is soft and friable, and suitable only for light foundation work.

Statistical Data of the Cray Quarry.

Amount of capital invested: Nothing.
Average number of employees: 2.
Wages paid different classes of employees: $1.00.
Average value of each grade per cubic foot: Sold at the quarry in the rough at $2.00 per cord.

DURAND AREA.

The local demand for foundation stone at Durand has been supplied by two quarries owned respectively by John Poeschl and P. E. Hardy. The quarry of John Poeschl is about half a mile south of the city, at the top of a bluff adjacent to the

Chippewa river. The rock is much broken up, and only suitable for light foundation work. The quarry owned by P. E. Hardy is likewise at the top of a bluff, about half a mile northeast of the city. The stone is somewhat harder than that at the Poeschl quarry, has a brown color, and is somewhat calcareous. The beds are from 6 to 12 inches thick, and are considerably broken up by the numerous joints, which strike N. 67° E. and N. 30° W. The sandstone beds are interlaminated with clay. The stone is suitable only for ordinary foundation work.

PORTLAND AREA.

Two quarries are located about two miles northwest of Portland, one owned by John McCormick and the other by Geo. Yergus. The upper beds of these quarries are Lower Magnesian limestone, underneath which occur beds of brown limonitic sandstone. The stone is soft and somewhat streaked with iron oxide, being suitable only for light foundation work.

SADDLE MOUND AREA.

The quarry of the Saddle Mound Sandstone Co. is located at Saddle Mound, Jackson county. The quarry was opened a number of years ago by a company, of which Levi P. Withee of La Crosse was president. The quarry was equipped with an engine and four or five gang saws, and three hand derricks. Stone was furnished for paving, monument bases, and building purposes. It was used in the United States Indian School and other buildings at Tomah, the Penitentiary at Waupun, and the C., M. & St. P. Ry. station at Whitewater. The quarry has not been operated for a number of years, owing to the general business depression.

Statistical Data.

Amount of capital invested: $50,000.00.

Facilities at hand for quarrying: 1 12-H. P. engine; 4 or 5 gang saws; 3 hand derricks.

MADISON AREA.

The sandstone quarried in the vicinity of Madison comes mainly from the upper beds of the Potsdam, known as the Madison sandstone. The Madison sandstone is found in beds varying from 1 to 2 ft. in thickness, and can be quarried in any reasonable dimensions for small constructional purposes. The quarries are owned by the City of Madison, David Stephens, and Edward Paunack. In each of these quarries, the stone has essentially the same characteristics. The stone has a light buff color, and is fine grained and calcareous, approaching a soft arenaceous limestone.

The stone cuts and dresses quite readily, and has been used to a very large extent for basements, trimmings, and walls to buildings in the city of Madison. The stone is quarried by blasting and wedging, and is hauled to the city by team. Difficulty is experienced in quarrying stone of sufficient thickness to make twelve inch coursing stone across the bed. For this reason the stone in most of the buildings thus far constructed has been laid on edge.

This improper method of laying the stone has resulted in the scaling of the stone, in the lower courses of some of the more important public buildings of the city. The stone has a very pleasant buff color, and when properly quarried and dressed serves as a very good building material. The Ladies' Hall, University Hall, and North and South Halls of the University, and several of the larger churches and business blocks in Madison, have been constructed out of stone from these quarries.

BLACK CREEK AREA.

At Black Creek, Outagamie County, there is located a small quarry of brown or gray sandstone owned by Henry Herman. The stone occurs in layers from six to twelve inches in thickness, about four or five feet below the surface. Underneath the beds at this depth, the stone takes on a lighter color and becomes finer grained. At a depth of nine feet the beds reach a thickness of twelve inches.

The sandstone from this, as well as from many other quarries of this region, is very well suited for side walks and cross walks. It does not have the disagreeable feature of wearing down to a slippery surface, as is the case with the limestone flags. It is not quarried quite as cheaply as the limestone but, when firmly compacted and well cemented with silica, it is one of the most desirable stones for side walks.

The stone from this quarry is used mainly to supply the local demand for foundation stone.

WESTPORT AREA.

At Westport, on the SE. ¼, Sec. 10, T. 8, R. 9 E., about 6 miles from Madison, is located a quarry from which a beautiful buff colored stone was at one time quarried. The stone taken from this quarry was used in the construction of the Federal building at Madison, which is in as excellent condition today, as it was when first constructed. It is reported that the stone from this quarry has been practically exhausted.

RÉSUMÉ.

In general, the Southern Potsdam sandstone region contains but little available stone, which is suitable for fine constructional work. Much of the stone is strong and durable, but on account of the cost of cutting and dressing, very little of it is suited for any but rough foundation, bridge, or pier work. The exceptions to this rule are found at Dunnville, Ablemans, and Madison, where very good building stone is quarried. By selecting the best stone, at the different localities, it is possible to find an abundance suitable for most local demands throughout the region.

It is a very mistaken idea held by some people that any stone which is strong and durable is suitable for building purposes. One ought to have an appreciation of the beautiful in stone work, as well as in wood work. Where beauty is one of the ends of architecture, coarse, soft sandstone, which dresses poorly, ought not to be used. There is an abundance of more

beautiful stone, that is easily cut and dressed, in other parts of the state, which should be used.

None of the quarries in this region, except that owned and operated by the C. & N. W. Ry. Co., is suitably equipped for quarrying stone for building purposes. As has been stated, the quarrying is done mainly by blasting and wedging, and the stone is broken into the required dimensions by heavy hammers and sledges. In this way much of the stone is destroyed, and that which is not completely destroyed, is unnecessarily injured.

THE ST. PETERS SANDSTONE.

The St. Peters formation, in this state, contains much less dimension stone and has a much more limited surficial distribution than the Potsdam, being found only in a comparatively narrow strip, extending from the Menominee river, in the northwestern part of the state, in a southerly direction as far as the state line, thence west as far as the Mississippi river. Small outliers of the sandstone are found in St. Croix and Pierce counties, in the western part of the state. (See general map, Plate I.)

The color of the sandstone is either white, brown, red, or yellow. It is generally medium or coarse grained, and, as a rule, is unconsolidated. It is often so friable that it crumbles easily between the fingers. On account of its soft friable character, it is difficult, in most places, to obtain sound blocks of any reasonable size.

At only two places, is the St. Peters sandstone quarried to any extent for building or other constructional purposes. One of these places is Red Rock, a small station about 5 miles east of Darlington, and the other is Argyle, in the eastern part of La-Fayette county.

DARLINGTON AREA.

THE DARLINGTON STONE CO.

The quarry located at Red Rock is owned and operated by the Darlington Stone Co. The beds of sandstone at this place are folded and show part of a synclinal trough and an anticlinal dome. The uppermost beds dip about 30° on one limb of the syncline, and 35° to 40° on the other. The rock is faulted many times, in a very complex and interesting manner. The color of the stone is widely different in different parts of the quarry. The upper beds are buff colored; the beds immediately below are streaked with purple, white, and buff; the beds below these are a brick red color, while still lower occur various shades of red and purple. The stone, in the lower part of the south limb of the synclinal trough, has a comparatively uniform color, a brilliant red with a tinge of purple. The stone in other parts of the quarry is spotted and streaked, alternating beds of purple and buff being common.

The stone is of medium hardness, but in places it is somewhat shaly. Lichens grow upon the surface of the natural exposures, while chisel marks of twenty-five years ago are as perfect today as they were when first made. Holes, drilled into the rock to blast the stone in making the railroad cut, are also apparently as perfect as they were when made 40 years ago.

The variegated stone has found a considerable market in Chicago and elsewhere, where it is used in random rubble walling. The variegated stone is not channeled, but is blasted and sold in blocks of irregular shape, ordinarily known as ton stone. The stone thus quarried is placed in the walls, in the most irregular shape, and with as great a variety of coloring as it is possible to obtain. The stone from the beds that are uniformly colored is channeled and sold in mill blocks.

The stone from this quarry has not been tested, and none of the buildings which have been constructed out of the stone have been examined. From the general appearance of the stone and the quarry it appears that a considerable amount of good dimen-

sional stone might be obtained for ashlar walling, although there is a large amount of undesirable stone associated with the better grade.

ARGYLE AREA.

SHERRILL'S QUARRY.

The quarry which is owned and operated by E. F. and B. R. Sherrill is located on the south side of the Pecatonica river about half a mile west of the depot at Argyle. The stone is of essentially the same quality and has the same variegated coloring, as that which is quarried at Red Rock. The quarry has quite heavy stripping, and a considerable percentage of poor stone, all of which it is necessary to remove in order to quarry the better grade of stone underneath. The strata at this place constitute the limb of a fold, which dips about 15° southeast. Faulting is very common.

The uppermost beds, 20 ft. in thickness, have a yellowish brown color. The color of the stone in the beds below these is reddish brown, brick red, and purple.

Two gang saws have been used in quarrying the stone, although most of it has been extracted by blasting. The main difficulty in the economical working of the quarry is the amount of stripping and the large percentage of poor stone that must be handled in order to obtain the better grade.

Laboratory Examination.

The Dressed Sample.—The sample which may be seen in the laboratory of the survey has a reddish brown color, and dresses very nicely. Occasional small secretions of iron oxide are the only apparent irregularities in color.

Microscopical Examination.—The microscopical examination of the thin section shows the stone to be composed of medium sized grains of sand, perfectly rounded and cemented with iron oxide. The individual grains of quartz give no evidence of being cemented with silica. Plate LXVI., Fig. 2, shows nicely the texture and composition of the rock.

Physical Tests.—Chapter VIII., Table V., gives the specific gravity and porosity of the samples tested in the laboratory. The average specific gravity of the rock is 2.659. The average ratio of absorption is 8.84 per cent., while the porosity is 19.06 per cent. This is below the average of the sandstone from the Lake Superior region, and shows that the rock is fairly well compacted for a coarse grained sandstone. The samples which were subjected to alternate freezing and thawing showed an average loss in weight of 1.45 grams on a mass of about 245 grams. This loss is somewhat greater than that recorded for any of the other sandstones, and may be a result of the somewhat incoherent character of the rock. The result of alternate freezing and thawing on the crushing strength is given in Chapter VIII., Table VII., and shows an average loss of 1,953 lbs. per sq. inch.

The average crushing strength of the fresh samples, given in Table II., is 4,173 lbs. per sq. inch. This crushing strength is a little lower than the average for sandstone of the Potsdam series, but is still sufficiently high to warrant its use in all but the heaviest structures.

The laboratory examination of the sandstone from this quarry indicates that care should be exercised in selecting the stone, some of it being too loosely compacted to be suitable for other than the lighter kinds of constructional work. Stone from other beds in the quarry is better adapted for building purposes, and is less liable to suffer from exposure to the atmosphere.

Statistical Data.

Amount of capital invested: $5,000.00.

Facilities at hand for quarrying: 1 12-hp. engine; 2 gang saws; 1 steam derrick; 1 hand derrick; 1 gang saw for sawing from solid bluff.

Average number of employees: From 4 to 10.

Wages paid different classes of employees: $1.50 to $2.25.

Cost of cutting and dressing stone per square foot:

Sawn and split into Ashlar, ready for wall	$.10
Ribbed and squared without margin	.20
Pointed and squared without margin	.15
Ax-hammered or crandled without margin	.20
Bush hammered or chiseled without margin	.20

Add $.05 for margin.

Cost of transportation: Per cu. ft. Freeport, $.04½; Rock Island and Moline about $.09.

Average value of each grade per cubic foot: Promiscuous blocks, $.20 to $.25; mill. blocks, $.30 to $.35; dimension blks., $.35 to $.40.

MISCELLANEOUS QUARRIES.

The St. Peters sandstone is quarried at a number of other places in the southern part of the state. At Mineral Point the sandstone is sufficiently compacted to be used for building purposes in and about the city. Many of the older buildings, including the Methodist church, which was constructed in 1867, are built out of the St. Peters sandstone. The sandstone in this vicinity has a brown color in some places, while in others it is yellow or white. When stone is desired for any particular purpose, the quarrymen are in the habit of searching the bluffs adjacent to the city until they find stone which is thought to be suitable in color and texture. They then quarry it, bring it into the market, and deliver it for the specific use for which it was quarried. In most places the sandstone is not regularly bedded, and is consequently difficult to quarry without machinery.

RÉSUMÉ.

In general, the sandstone from the St. Peters formation is very soft, but when sufficiently hard to be dressed and placed in the wall, it will, apparently, remain permanent for many years. The durability may be partly attributed to the crust which forms on the surface of the rock during the seasoning process. Like the Potsdam sandstone, the St. Peters is not, as a rule, susceptible to fine dressing, and is only in exceptional localities suitable for the better kinds of architectural work. For the purpose of supplying local demands, in the way of culverts, foundations, etc., its accessibility makes it an important resource.

In many places the St. Peters sandstone was used for building in the early days, because it was close at hand, and could be had for the expense of quarrying. Brick and lumber at that time were expensive, and therefore seldom used for construc-

tional purposes. This accounts in a measure for the great number of rough stone buildings which are found throughout this sandstone region. The conditions are now reversed, and it is possible to obtain brick and lumber cheaper than stone, and, for this reason, the facings of all the new buildings are brick, while stone is used only in the back walls, and for foundations and trimmings.

CHAPTER V.

LIMESTONE.

A large part of Wisconsin is immediately underlain by limestone, which extends in a broad belt through the eastern, southern, and western parts of the state, being composed for the most part of Lower Magnesian, Trenton, and Niagara. There is a wide variation in the texture and chemical composition of the limestone from these different formations. In some places the stone is coarse and sugary, while in others it is dense and finely crystalline. Most of the limestone is composed of calcium magnesium carbonate, although occasionally the percentage of magnesium is small. Limestone, rich in calcium magnesium carbonate, is ordinarily called dolomite, or magnesium limestone, while that in which the percentage of magnesium is small is called a limestone. The origin of limestone and dolomite is discussed in the appendix, and it will hardly be necessary to consider it in this connection. The limestone and dolomite in Wisconsin probably owe their origin to several causes, organic, chemical, and mechanical.

The suitability for building purposes of the limestone, from different parts of the same formation, as well as from the different formations, is widely different. The different beds of a single formation may have very different textures and compositions, and the individual beds themselves may vary within short distances. A definite statement as to what particular beds or horizon, of the different limestone formations, will furnish the most desirable building stone cannot be made.

The limestone from certain parts of the state is very closely compacted and thoroughly crystalline, often resembling marble.

Such limestone often occurs in relatively small dimensions, and is generally difficult to cut and dress. Limestone from other places has a loose, open texture, and is consequently softer and more readily worked. The stone from parts of certain formations is undesirable on account of the presence of deleterious minerals. Portions of other formations furnish stone with a porous, vesicular texture, which unfits it for most uses.

The color of the limestone from the different formations ranges from buff or straw yellow to dark bluish gray. As a rule, the color is quite uniform throughout any single horizon in the quarry, and is often the same for a number of beds.

The largest percentage of the quarries in the state are in the limestone region. The limestone is not utilized exclusively for building purposes, but from it there is manufactured a very large amount of quicklime and macadam. The limestone is in many places especially adapted to the manufacture of quicklime, and in 1896 the total output was valued at $314,704.00.[1] Much of the limestone, which is burned in the kilns of the different factories, is well suited for building purposes.

The limestone product is drawn mainly from three Silurian formations, the Lower Magnesian, the Trenton, and the Niagara. In the following pages these different formations will be treated separately, and an attempt will be made to give the important characteristics of the stone as it is obtained from each; the strength, durability, and possibilities for extensive quarrying.

THE LOWER MAGNESIAN.

The Lower Magnesian formation rests conformably above the Potsdam Sandstone, and is overlain by the St. Peters. An idea of the surficial distribution can be best obtained by reference to the general map, Plate I. The area is very irregular in shape, and extends through the eastern, southern, and western portions of the state, either as a continuous outcrop, or as isolated out-

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[1] Mineral Resources of the U. S.; 18th Ann. Rept. of the U. S. G. S., 1896-97, p. 1044.

liers capping the hills of Potsdam sandstone. Many of the bluffs and ridges in the south central part of the state and along the Mississippi river are either capped with, or almost entirely composed of the limestone of this formation. In the south-western part of the state the formation is largely concealed beneath the Trenton and later formations, while farther to the north the strata die out and are replaced by beds of Potsdam sandstone.

The beds at different horizons in this formation differ quite largely from one another. Certain of the beds are characterized by an even, fine grained texture, compact, and generally free from cavities. These beds are frequently of considerable thickness, and can be quarried in very large dimensions. Other beds have what is known as a hackly character, being characterized by numerous small irregular cavities which make the stone difficult to work, and which destroy its beauty. Other beds are characterized by numerous hard chert nodules which likewise injure the stone for economic purposes. In general, it may be said, that the most desirable stone for constructional purposes is obtained from the fine, evenly bedded courses, such as were first mentioned above.

The following section, taken from Vol. II., Geology of Wisconsin, p. 672, gives a good, general idea of the succession in the western part of the state, where the most desirable stone is quarried.

	FEET.
1. Slope of hill (to top of vertical cliff). Composed of heavy bedded light gray Magnesian limestone. Stratification quite regular, contains no planes. Good building stone....................	23
2. Hard, compact, heavy bedded, light colored limestone. Lines of stratification not distinct. Full of irregular masses of flint, which compose about half of the bed. Exposed in vertical cliff	33
3. Slope of hill covering limestone. Not well exposed.............	23
4. Coarse grained limestone. Weathering irregular on exposed surfaces. Contains a few flints disseminated through it, and occasional druses of quartz................................	7
5. Gray limestone. Very hard and compact. Regular stratified beds are 1 to 2 feet thick. Contain no flints.................	29

	FEET
6. Crystalline gray magnesian limestone, with a few flints, irregularly disseminated. Beds 2 feet thick	9
7. Hard, light colored limestone, crystalline in texture, weathering but little on exposure. Beds about 3 feet thick. Contain no flints	46
8. Fine grained, straw colored, slightly arenaceous, magnesian limestone. Beds about 1 foot thick. Stratification quite regular.	20
9. Irregularly bedded dolomitic limestone. Has sometimes oolitic structure	26
10. Yellow arenaceous limestone. Transition beds. The sand appears in rounded grains separate from one another and cemented together with lime. Stratification indistinctly marked.	23

The above section, which was taken from a bluff at the mouth of the Green River, situated in the NW. ¼ of Sec. 22, T. 7, R. 4 W., probably reaches almost to the top of the formation, since considerable sandstone was found scattered along the summit of the bluff. As one proceeds north from this point the upper beds are missing, until finally, as we examine the most northern outcrops, only the lowest beds remain.

It is to be noted that many of the beds of this formation contain very irregular masses of flint and often druses of quartz, each of which injure to some extent the value of the stone for the finer kinds of work. It is only the heavy bedded, uniformly colored layers, free from druses and flint nodules, that furnish the most satisfactory building stone.

It would be impossible in a report of this kind to consider in detail the numerous quarries which have been opened at one time or another in this formation. Quarrymen have worked in one locality for a year or two, and then deserted it for a locality where the prospects appeared better. In this way many openings have been made in all parts of the area. In certain of these localities quarrying has been carried on almost continuously for a great many years, while in others operations have only been conducted for a few years.

The bluffs adjacent to the Mississippi river are dotted with quarries, many of which contain an abundance of stone, suitable for a variety of purposes. None of the quarries have been very

extensively developed, on account of several conditions incident to their location. In the first place the bluffs are of considerable height and somewhat steep. A heavy talus usually covers the lower ledges, almost to the top of the bluffs, on account of which the accessible rock is mainly near the summit. Provided the talus is at a much lower level, the stripping may be very heavy, making it impracticable to quarry stone from the lower beds. If suitable stone can be obtained from the uppermost beds, the necessity of hauling it a considerable distance to the valley below hinders profitable exploitation. Difficulty is further experienced in opening a quarry near the summit of these bluffs, on account of the lack of a floor on which to commence operations. Thus it appears that if the durable stone occurs at or near the top of the bluff, the difficulty in opening the quarry and the distance to the bottom of the hill militate against profitable operation; while if the stone occurs at the foot or near the middle of the bluff, the stripping is too heavy for removal. If it were not for these conditions, one might expect to find more important quarries along the bluffs of the Mississippi river. Away from the river the limestone is not so generally exposed, and the beds are not composed of so desirable stone.

The most important quarries in this formation are those at Bridgeport, Maiden Rock, LaCrosse, and Trempealeau. Other quarries are located at Fountain City, New Richmond, Bluff Siding, Marshland, Hortonville, Medina, Arcadia, Osceola, Onalaska, and Madison. The last named quarries have been operated for local consumption, and represent only a few of the many quarries in the Lower Magnesian formation.

Description of Individual Areas.

BRIDGEPORT AREA.

The quarries in the vicinity of Bridgeport are situated along the bluffs adjacent to the Wisconsin river. All the stone suitable for building purposes is quarried from a single horizon, having a total thickness of from 12 to 16 ft. The beds of this

horizon are continuous along the bluffs, almost the entire distance from Bridgeport to Prairie du Chien.

This stone is an arenaceous limestone, and has a light buff or straw yellow color. It is of medium hardness, and works quite readily under the chisel. It contains occasional druses of quartz, but they are not sufficiently abundant to very materially injure the rock. The joints strike N. 40° W. and N. 45–50° E.

Laboratory Examination.

Microscopical Examination.—Thin sections were cut from this stone and examined under the microscope, showing that the stone was composed essentially of calcium carbonate and occasional small irregular grains of quartz.

Physical Tests.—Two inch cubes, which were crushed in the testing machine, stood a pressure of 10,112 lbs. per sq. inch on bed, and 7,508 lbs. per sq. inch on edge. (See Chapter VIII., Table II.) Samples of the limestone were also tested to determine the transverse strength, the results of which are given in Chapter VIII., Table III. The modulus of rupture was determined to be 1,164.3 lbs. per sq. inch.

The average specific gravity of the rock, as given in Table V., is 2.743. The ratio of absorption is 5.51 per cent., while the porosity is 13.19 per cent. Samples from the same bed were subjected to alternate freezing and thawing, but showed no loss in weight. The average loss in strength was only 571 lbs. per sq. inch. (See Chapter VIII., Table VII.) Other samples, which were subjected to extreme heat were little injured up to the point of calcination. Small cubes were tested to determine the effects of sulphuric and carbonic acid gases. These results, given in tables VIII. and IX., indicate that these gases have practically no effect on the limestone.

The above laboratory tests show that the strength and durability of the rock are sufficient to warrant its use in the construction of buildings, bridges, and piers.

LOWER MAGNESIAN LIMESTONE.
Wisconsin State Capitol, Madison, Wis.

Description of Individual Quarries.

Two quarries have been opened in the limestone of this area, known as the Bridgeport Stone Quarry and the Maustin Quarry. Both are situated on the north side of the Wisconsin river immediately adjacent to the tracks of the C., M. & St. P. Ry.

BRIDGEPORT STONE QUARRY.

The Bridgeport Stone Quarry is located half a mile west of Bridgeport, and is owned and operated by Thomas P. Norton, of Spring Green, Wis. The quarry was opened about the year 1856, and is one of the oldest quarries in that part of the state. It has been worked more or less each year since it was opened.

The quarry consists of one opening about 300 ft. long, 60 ft. wide, and 28 ft. deep. The quarry faces the south, and has a covering of clay and soil from 2 to 8 ft. thick. Immediately underneath the stripping there are about 10 ft. of limestone, much broken, and classed as stripping. Below this occur from 14 to 17 ft. of uniformly bedded limestone, varying in thickness from 1 to 4 ft., which may be gotten out in any dimensions up to 4 or 5 ft. The stone generally has a firm, even grained texture, and is cream colored. Small, drusy cavities, lined with small crystals of quartz, are of occasional occurrence. The uppermost beds of this horizon are freer from imperfections than the lower, and furnish the best stone for cutting and dressing.

The samples which were used in testing the stone from this area were obtained from this quarry. It will not be necessary at this place to repeat the tests, as they will be found in the tables in Chapter VIII. The quarry is prepared to furnish stone for all ordinary constructional purposes, such as bridges, piers, buildings, curbs, and foundations.

Stone from this quarry has been used in the construction of the State Capitol at Madison, Wisconsin, the Normal School building at Madison, S. Dak., the Dousman House, at Prairie du Chien, and many of the bridge piers on the C., M. & St. P. Ry. In no case is there evidence that the stone has suffered unwarranted injury from atmospheric agencies. The best stone

appears to be in all respects suitable for the purposes for which the quarry is prepared to furnish stone.

MAUSTIN QUARRY.

The Maustin Quarry is located one mile west of Bridgeport, and is adjacent to the C., M. & St. P. Ry. The quarry is owned by Wm. Powers, of Patch Grove, Wis., and was opened about 1855. It was operated almost continuously from that time until 1885, when operations were indefinitely suspended. One opening has been made about 150 ft. long, 25–30 ft. wide, and about 20 ft. deep.

The stripping is from 6 to 12 ft. deep. Immediately below this occur 12 ft. of uniformly bedded stone, similar in all respects to that which is exploited from the adjacent quarry. The joints are a considerable distance apart, allowing very large lateral dimensions to be quarried. The beds are generally from 1 to 2 ft. thick, but in places the bedding planes are tight, and greater thicknesses can be obtained. The quarry is not being worked at present, owing to the general depression in the stone industry.

Stone from this quarry has been used in the construction of the State Capitol building, Madison, Wis., in the Minneapolis stone arch bridge, Crawford County Court House, St. John's Sacred Heart College of Prairie du Chien, St. Mary's Academy at Prairie du Chien, and a number of other important buildings.

General Considerations.

Ordinarily the limestone of this area occurs in large enough dimensions and of sufficiently uniform quality to be satisfactory for most constructional purposes. The transportation facilities are much better than those of many other quarries in the limestone region of this state, and if properly managed considerable business ought to be developed at this place.

MAIDEN ROCK AREA.

The principal quarry at this place, owned and operated by Mr. Lester, is situated near the summit of a high bluff adjacent

to the Mississippi river. The stripping, which includes the upper beds of the formation, is somewhat heavy, varying from 5 ft. at the ends to 25 ft. in the middle. Immediately beneath the stripping are 10 ft. of uniform fine textured limestone. The stone is soft and can be gotten out in very large dimensions, and sawed into blocks of any required size. The stone has a delicate creamy color, and is very finely porous.

The stone is quarried mainly by blasting and wedging. It is hauled by team to the foot of the hill, at which place a mill has been erected for sawing the stone into blocks of any required size.

The strength and durability of the stone was not determined, on account of the failure of the owner to send the samples requested. Therefore its value as a building material can only be inferred from its general appearance. The stone has lately been used quite extensively in Minnesota and Wisconsin, and to the best of our knowledge has given good satisfaction.

TREMPEALEAU AREA.

The main quarry at Trempealeau is situated near the summit of one of the bluffs adjacent to the city, and is similar in location to the other quarries along the Mississippi river. The ascent to the quarry is, by a long winding road, somewhat of a breathless climb. The stripping at the quarry is from 2 to 4 ft. deep, and consists of loose boulders and dirt. Immediately below the stripping are from 14 to 18 ft. of fine textured, compact limestone, resembling very much white sandstone. An occasional drusy cavity lined with quartz is the only noticeable defect in the stone. The beds immediately below this are from 10 inches to 2 ft. thick, with a total thickness of 6½ ft. They are rough and vesicular, but can be easily quarried in large dimensions suitable for heavy footing stone. The stone is hard and somewhat refractory, and consequently dresses with considerable difficulty.

The most desirable stone for building purposes is taken from the upper beds in the quarry. This is now used mainly for monument bases and brick trimmings. The stone from the

hackly horizon was used in the construction of the new wagon bridge at LaCrosse, and is considered well suited for such a purpose. The possibilities of securing a large amount of excellent stone from this quarry are good, and it is thought that the quarry might be worked to advantage on a more extensive scale than at present. The necessity for better facilities for quarrying and an easier method of transportation from the top of the bluff to the valley below is quite evident.

FOUNTAIN CITY AREA.

Three quarries are located at Fountain City, one of which is owned by Oenning & Giesen, another by Jacob Secker, and a third by Albert Kirchner. All of these quarries are located near the summit of the bluffs, about ¼ of a mile east of the town. The stone which is quarried from the different openings is essentially the same, being a buff colored limestone.

Oenning & Giesen's quarry, which may be taken as an example of all the quarries at this place, has a small depth of soil covering, beneath which are about 10 ft. of rip-rap. Below this occur about 9 ft. of heavily bedded hackly limestone, having a grayish blue color, streaked occasionally with brown. Below this are 7 ft. 8 in. of fine grained whitish limestone, much softer than the stone in the beds above. Only the lower 14 in. of this course is vesicular and rough, like the blue hackly limestone above. Beneath this bed occur 16 ft. 4 in. of heavily bedded, hard, hackly, gray limestone.

The bed immediately beneath the rip-rap is the easiest to cut and work, although it contains occasional chert nodules, and small drusy cavities lined with quartz. The lower beds, which are from 6 in. to 2 ft. in thickness, furnish excellent stone for bridge work. All the stone is used for footing, foundations, and buildings, but those beds which have an irregular texture, occasioned by chert nodules and drusy cavities, are not suitable for cutting and dressing.

Statistical Data of Oenning & Giesen's Quarry.

Amount of capital invested: $400.00.
Average number of employees: 4.
Wages paid different classes of employees: $1.50.
Average value of each grade per cubic foot; Dimension, $.15.

ONALASKA AND LA CROSSE AREA.

The supply of stone for foundation and building purposes in La Crosse has been drawn mainly from a number of quarries, located on the bluffs north and south of the city. The stone has essentially the same characteristics in all the quarries and is exploited only when specifically contracted for.

The stone occurs ordinarily in beds from three inches to three feet in thickness, but none of the beds above eight inches consist of clear, uniform textured stock. Several sets of joints occur in some of the quarries. In the quarry owned by George Pierce of Onalaska, located in the N. W. ¼ of N. E. ¼ of Sec. 34, T. 17, R. 7 W., the joints strike N. 45° W., N. 45° E., N. 70° W., and E. and W.

The limestone has a dense, grayish blue color. It is hard and brittle and often contains small drusy cavities lined with quartz. The jointing planes are generally stained brown with iron oxide. The stone is cut and dressed with difficulty and can be used to best advantage in rock face work.

The stone is suitable mainly for light footing, foundation, and building. For the last purpose it should be carefully selected and quarried with care. The thickness of the beds suitable for building stone, limits its use to small structures.

The principal quarries at La Crosse are owned by Wm. Niemeyer and Ebner, Mr. Pammel and Wm. Clause, Mr. Anderson, Mr. Nelson, Mr. Marquart, and Peters and Wahl.

The main quarries at Onalaksa are owned by George Pierce, Will Kenyon, and Mr. Brunner.

OSCEOLA AREA.

The stone quarried in the vicinity of Osceola comes mainly from the limestone beds near the top of the bluffs adjacent to the

St. Croix river. The main quarry is about a mile south of the city, and is owned by Mr. Woll. The stone is a rough, somewhat hackly limestone. Several buildings in Osceola have been constructed out of the stone, and although they are not elegant, yet the walls are strong and durable. The stone has a yellowish brown color, and a fairly uniform texture. The lack of machinery makes quarrying difficult, and the stone is therefore somewhat expensive for building purposes.

The greenstone, which is found in this vicinity in large fragments broken from adjacent exposures, is used to some extent for foundation purposes in place of the limestone. It can be obtained without the necessity of quarrying, and is equally as strong and durable as the limestone.

HUDSON AREA.

The bluffs adjacent to the Mississippi river at this place are mainly composed of sandstone, capped with Lower Magnesian limestone. The limestone has been used quite generally in the older buildings of the city, but is now used only for rough foundation work. The old stone buildings and retaining walls are built out of roughly dressed stone. The joints were large, and the blocks often irregularly fitted together, on account of which the buildings now have a somewhat dilapidated appearance. It is hardly possible that the stone will henceforth be used for any but foundation purposes.

MARSHLAND AND BLUFF SIDING AREA.

Near the top of the bluff at Marshland, a small quarry is operated by Mr. Henry Felker, to supply a local demand. At Bluff Siding, about 2½ miles north of Marshland, is a quarry owned by J. W. Willis, of Winona. As elsewhere, the stone is quarried near the summit of a high bluff. The stone is used mainly for the manufacture of quick-lime, although rough stone has been furnished for masonry work. The following is a section of the quarry from the bottom to the top:

3 ft. Fine texture. Beds are from 10 to 14 in. thick. Color is grayish white. The appearance of the stone from these beds is very favorable.

14 ft. Heavily bedded, hackly limestone. Beds are about 4 ft. in thickness. This stone might serve for footing or foundation work.

4 ft. Compact limestone. Fine grained. Beds are from 12 to 14 inches thick.

The rock above this for about 40 ft. appears to be mainly rough hackly limestone, scarcely suitable for any other purpose than the manufacture of lime.

ARCADIA AREA.

Three small quarries are located in the vicinity of Arcadia, owned respectively by Fred Blessner, Wm. Fernow, and Mr. Kube. The quarry owned by Fred Blessner is immediately north of Arcadia, near the summit of a high bluff. All the stone is quarried from the lower beds of the Lower Magnesian limestone, and the upper beds of the Potsdam sandstone. The quarry is small and the stone only used for local consumption. Kube's quarry is about 5 miles south of Arcadia, and Wm. Fernow's is about 7 miles west. The stone at these places is quarried simply to supply the local demand.

NEW RICHMOND AREA.

Two quarries are located near New Richmond, owned respectively by Wm. McDonald and Levi Oakes.

McDonald's quarry is about 2½ miles northwest of the city. The stripping of soil is from 6 to 10 feet deep, below which is a bed of somewhat hackly limestone from 3 to 6 inches thick. Below this is a bed of finely crystalline limestone, 8 inches thick. Underneath this are three beds,—one is arenaceous limestone, 1 ft. 5 in. thick, the next is hackly limestone, 1 ft. 8 in. thick, and the last is arenaceous limestone, 1 foot thick.

Oakes' quarry is about one mile south of New Richmond, and shows nothing but rough hackly limestone. The stone in both of these quarries is suitable mainly for rough foundation work. An abundance of stone for this purpose can be obtained from either quarry.

MEDINA AREA.

The quarry at Medina is owned by Mrs. Wm. Youngs. It is located about half a mile south of the village, and is connected with the railroad by a spur. The beds are rough and somewhat vesicular, the stone having been used mainly for flagging purposes.

The opening is very irregular, being 240 ft. long, 240 ft. wide, and 4 ft. deep. A stripping of about 5 ft. of light soil occurs at the surface. The stone occurs in layers from 3 to 6 in. thick, of which 12 have been worked. The lower two feet of the quarry is somewhat massive, but very rough and irregular, containing numerous cavities filled with drusy calcite and quartz. The joints strike about N. 20° W., N. 38° E., and N. 70° E. They are from 3 to 5 ft. apart, and break the stone into dimensions that can be easily handled, and yet sufficiently large for ordinary purposes. The color is somewhat irregular, being a bluish buff color mottled with irregular spots of yellow.

Blocks, suitable mainly for flagging purposes, of almost any reasonable dimension, can be quarried. At one time a very considerable amount of stone was sold from this quarry, but it has now been abandoned for several years.

DALE AREA.

The quarry at Dale is owned by D. H. Balliet of Appleton. Two openings have been made, but neither has been very much developed. The stone is quarried mainly from beds near the surface, and, so far as exposed, the layers are thin, being from 3½ to 4½ inches in thickness. The stone is irregularly jointed, the seams striking about N. 38° W., and at right angles to this direction. The first set occurs at intervals of from 5 to 10 feet, and allows the quarrying of large sized flagstones. The surface of the stone is rough and irregular, but the texture, with the exception of occasional drusy cavities, is comparatively uniform. At the second opening the beds are from 6 to 8 inches in thickness, and sufficiently uniform to be serviceable as light coursing stone. The stone is all finely crystalline, and mainly suitable

for sidewalks, foundations, and possibly light bridge and culvert work.

HORTONVILLE AREA.

A small quarry has been opened at Hortonville by Fred Mitchell and C. B. Benjamin. The limestone is immediately above the Potsdam sandstone, and is suitable mainly for rough foundation work.

D. Hodgins owns a small quarry at this place, but the stone is mainly burned for lime.

RÉSUMÉ.

In general, the quarries in the Lower Magnesian limestone formation have not been extensively developed. This condition is not due to a scarcity of desirable stone, but rather to its manner of occurrence. The clearest and best stone occurs in the western part of the state, either concealed beneath heavy talus slopes, or among the uppermost layers, capping the high bluffs and ridges along the Mississippi river. If the serviceable stone is near the bottom of the bluffs it is usually concealed by a talus, which is too heavy for removal. If the beds are exposed midway up the hill it is difficult to open a quarry on account of the steepness of the slope. But even if an opening could be made at such a place, the serviceable beds soon pass underneath a thickness of other strata, the removal of which would be too expensive for economical working. Only when the beds are at or near the top can they be worked to advantage. Here difficulty is also often met in making a floor on which to work. Everywhere in this bluff region the quarryman is confronted with the problem of getting the stone safely and economically from the top to the bottom of the hill. This is generally accomplished by using teams, sometimes by rolling. Very few of the quarries are equipped with gravity cars and tracks. Yet, where any considerable amount of stone is to be quarried, this is apparently the best method. It requires a small amount of capital to put in a track and purchase cars, but the transportation is so greatly facilitated that one is fully compensated for the extra invest-

ment. In order to avoid the heavy stripping which is so often met with in these bluff quarries, operations are generally extended along the side of the ridge or bluff, instead of back into the hill.

In the eastern and southern parts of the state, the quarries in this formation are not so numerous as in the western. Neither have they been so extensively operated. These conditions are largely attributable to three circumstances. The first is the proximity of the Trenton limestone, which, on account of its manner of occurrence, can everywhere be quarried easier than the Lower Magnesian. That stone which can be quarried with the least difficulty is generally the one most largely used, independent of its quality. Second, the eastern distribution of the Lower Magnesian limestone is largely concealed beneath a heavy mantle of drift. Third, the better beds of stone die out before they are followed a very great distance from the Mississippi river.

For these reasons, it is probable that, with the exception of certain isolated quarries in the western part of the state, the Lower Magnesian formation will never be very largely exploited for other than local purposes.

THE TRENTON LIMESTONE.

Stratigraphically, the Trenton formation immediately overlies the St. Peters sandstone, and underlies the Hudson river shale. This formation is more widely known as a source of building stone than either the Southern Potsdam or St. Peters formations, and is of correspondingly greater economic importance. The Trenton formation is ordinarily divided into two parts, the lower, known as the Trenton, and the upper, known as the Galena. The Trenton is further subdivided into the Lower and Upper Buff, and the Upper and Lower Blue beds. The distinction between the Galena and Trenton is not always well marked, and neither are the subdivisions known as the Buff and Blue beds very sharply defined. The average total thickness of the Trenton formation is about 280 ft. No attempt is

made in the following discussion to consider any of the various subdivisions. The stone from all the quarries, whether located in the Trenton or Galena, will be considered under the general head of Trenton.

The surficial extent of the limestone can be best understood by reference to the general map, Plate I. A cursory glance at this map shows that the Trenton formation, beginning at the Menominee river in the northeastern part of the state, extends southwest as far as the Illinois boundary line, and west nearly to the Mississippi river. A large part of the underlying rock in the southern part of the state is of this formation. The general area of Trenton does not extend further north than Crawford county, except in a few isolated patches which cap the bluffs of St. Peters sandstone in the northwestern part of Pierce and the southwestern part of St. Croix county.

A large number of quarries are operated in different parts of this formation, but the amount of stone which is shipped is comparatively small. The stone is largely used for local purposes, as in the case of the stone from the Lower Magnesian formation.

The Trenton limestone differs from the Lower Magnesian in being more uniformly bedded, and in having an originally blue color. The bedding planes are seldom smooth and regular, but are generally rough and uneven. The beds are characterized by an irregular wavy lamination, between the laminæ of which thin leaves of shale or clay frequently occur. It is not to be understood that the Trenton formation consists entirely of irregularly laminated limestone, but merely that this is one of the general characteristics of many of the beds. Certain of the beds are locally solid, and free from inter-laminations of clay. All of the beds of Trenton limestone are more or less fossiliferous, while certain thin layers are composed almost entirely of a mass of shell remains. The upper beds of the Trenton formation, known as the Galena, comprise the horizon from which the lead and zinc ores of the southwestern part of Wisconsin have been largely mined.

The subdivision of the Trenton into the Buff and Blue beds

is purely arbitrary. The Buff colored beds were originally blue, having attained their present color merely through weathering.

The extensive use of the stone from this formation for local purposes is probably due largely to circumstance. In the first place, the stone is more easily quarried than any of the associated rocks, on account of the pronounced bedding and the more fortunate occurrence of jointing planes. In the second place, the fact that very many of the important cities of the state are located within this region has been a very potent cause for its more extensive development than the Lower Magnesian. It should be noticed that within this formation are located Marinette, Green Bay, Kaukauna, Neenah, Menasha, Appleton, Oshkosh, Fond du Lac, Ripon, Beaver Dam, Watertown, Oconomowoc, Whitewater, Janesville, Monroe, Beloit, Mineral Point, Platteville, Darlington, and many other more or less important cities. Further, that portion of the state which is immediately underlain by the Trenton formation is one of the best agricultural regions of the state. This, combined with the natural water power at various points, has influenced the location and growth of some of the larger cities just mentioned. The southwestern and southern parts of the state are almost entirely covered with glacial drift, which was in large part derived from the Trenton and Lower Magnesian formations farther north. This has enriched the soil and made it excellent for agricultural pursuits. Thus the limestone formation itself has largely determined the condition of the soil, which in turn has assisted in the development of large cities, which, in their turn, have created a demand for the limestone to be used in the construction of buildings.

Description of Individual Areas.

From only one of the many quarry areas in this formation is the stone shipped to any extent. This is known as the Duck Creek area, and is located in Brown county about two miles and a half north of Green Bay. The local demand for stone in the

Fox river valley is largely supplied by quarries at Kaukauna, Neenah, Oshkosh, and Appleton. The remaining quarries in this formation supply stone only for local consumption. It will be our purpose to consider, first, the Duck Creek area, then the Fox River Valley area, and, lastly, in a general way, the individual quarries of the remainder of the region. For additional detailed information concerning this formation and the character of the rock occurring at different localities, the reader is referred to the volumes of the Geology of Wisconsin, where much more complete descriptions may be found.

DUCK CREEK AREA.

Three quarries have been opened in the Trenton limestone at Duck Creek, about 2½ miles north of Green Bay. (See Plate XL.) The quarries are located immediately adjacent to each other, and the stone from all the quarries is essentially the same, being taken from the upper beds of the Trenton, known as the Galena. The first quarry was opened about 1855, the second about two years later, while the third was opened in 1891. These quarries are generally operated the year around, and have been worked almost continuously since first opened.

Quarry Observations.

The stone is a magnesian limestone, and has a general bluish gray color. The bedding is usually uneven, being arched up in a number of places on the floor of the quarries. The partings, between the bedding planes, are emphasized by thin leaves of shale which increase the facility with which the beds are capped. The beds vary in thickness from 8 to 28 inches. Between some of the heavier ones there is an occasional thin layer of clay several inches in thickness.

The joints strike about N. 68° E. and N. 30° W., and occur sufficiently far apart to assure one of almost any desired lateral dimensions.

An occasional pink flinty lamina occurs between the dark blue beds, and small drusy cavities, lined with quartz and occasion-

ally containing sphalerite, pyrite, or iron oxide, are characteristic of some of the beds.

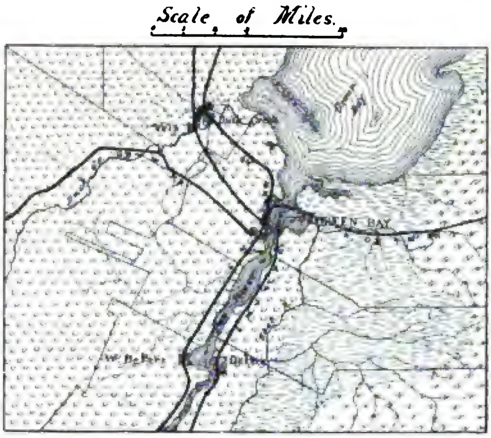
The companies operating at this place are the Gillen Stone Co., the Duck Creek Co., and the C. & N. W. Ry. Co. The Railway Co. has opened their quarry to the greatest depth, and the following section, taken from the top to the bottom of that quarry, indicates the general character of the stone from each of the three openings.

15 in. Considered one of the best beds of the quarry. Below this bed is ¼ or ½ inch of clay.
34 in. Sometimes runs solid, while at other times it is split into two or three courses.
16 in. Solid bed. Is never capped.
19 in. Works into good 18 in. coursing.
28 in. This bed is split up into any desired thickness.
11 in. This bed is shelly and worthless.
15 in. This bed differs in quality in different parts of the quarry. In some places it is suitable for dimension stone, and in other places it is shelly and worthless.

A section of the Duck Creek quarry, adjacent to the one from which the above section was taken, shows that the courses are essentially the same, differing only in minor details. The quarry of the Gillen Stone Co. is immediately adjacent to the Duck Creek quarry, and the courses likewise correspond in their general characteristics.

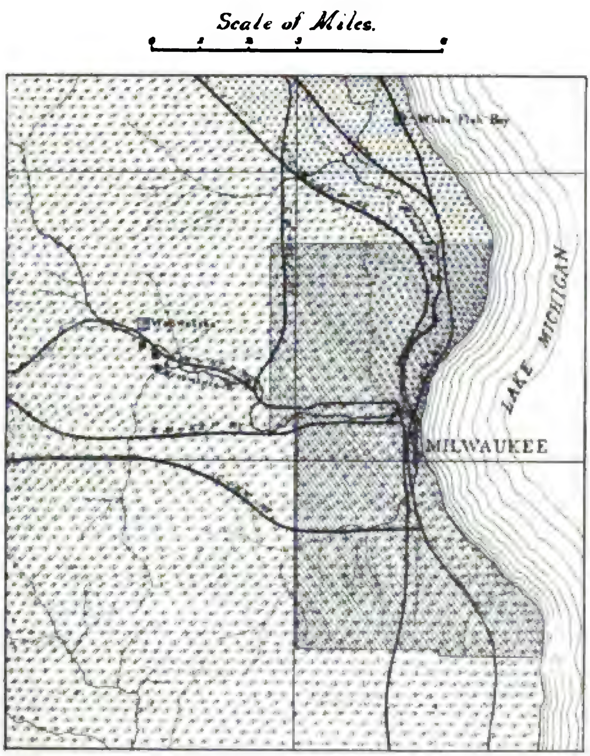
Laboratory Examination.

The Dressed Sample.—The limestone from these quarries is readily cut and carved and takes a very good polish. The sample in the laboratory of the Survey, from the Gillen Stone Co.'s quarry, indicates very nicely the character of the dressed work. The rock face is pleasing, and the buildings in which this style of work has been used look equally well. The color is pleasing and gives the stone a very attractive appearance. The hammer dressed surface is exceptionally fine, and suitable for the best kind of architectural effects. The carving is illustrated in Plate LIX.



Niagara | Trenton
Cincinnati | Quarry

DUCK CREEK AREA.



Devonian | Niagara | Quarry

WAUWATOSA AREA.

Microscopical Examination.—The microscopical examination shows that the limestone is well compacted, although not composed of grains of uniform size. One part of the section may be fine grained, and the other coarse. The stone is thoroughly crystalline, but shows occasional brownish streaks due to the presence of iron oxide. The rock also contains a very small amount of argillaceous material. The structure and details of the rock are well shown in the microphotograph, Plate LXIX., Fig. 1.

Chemical Analysis.—The following is a chemical analysis of the Duck Creek limestone, made by Prof. W. W. Daniells. The insoluble residue is 3.17%, while the argillaceous material reaches 1.95%, which is higher than that contained in limestone from other formations in this state.

$Si\ O_2$	3.17
$Al_2\ O_3$ / $Fe_2\ O_3$	1.95
$CaCO_3$	49.97
$MgCO_3$	44.58
	99.67

Physical Tests.—The specific gravity and amount of water absorbed are given in Chapter VIII., Table V. An examination of these tables shows that the average specific gravity is about 2.84, while the porosity averages 1.04%, and the ratio of absorption about .37%. The effects of alternate freezing and thawing are given in Chapter VIII., Table VI. The average loss in weight was .60% on a mass of about 393 grams. The difference in the crushing strength of the fresh and frozen samples is recorded in Table VII., of the same chapter. The result there recorded gives the frozen samples a higher crushing strength than the fresh ones. The reason for this is not the greater strength of the frozen samples, but the result of the way in which the fresh samples were crushed. The samples were first placed in a 100,000 lb. machine, in which the ultimate strength was not reached, and then removed and crushed in a 200,000 lb. machine. This resulted in giving a compressive

strength considerably lower than the stone is capable of standing.

Samples were also tested to determine the effect of sulphurous and carbonic acid gases. The results of these tests are recorded in Chapter VIII., Tables VIII. and IX. It will be observed that the loss in weight due to treatment with carbonic acid gas was imperceptible, while the treatment with sulphurous acid gas resulted in a loss of less than .03 of a gram on a mass of about 44 grams. Samples of the limestone were subjected to high temperature tests, with the results given in Chapter VIII., Table X. Certain of the cubes were heated to a temperature of 1,200° F., and, upon suddenly cooling, flaked off at the corners. (See Plate LVII.) Others remained uninjured, until they were calcinated. At a temperature of 1,000° F. the samples changed to a whitish color on the outer surface.

The crushing strength of the rock is given in Chapter VIII., Table II. It will be noted that the crushing strength is very high, almost equaling that obtained in the tests of the limestone from the Niagara formation. The average crushing strength is 24,552 lbs. per sq. in., which is considerably below the actual compressive strength, as explained on a previous page.

General Considerations.

In general, the results of the laboratory tests are very satisfactory, showing that the stone possesses not only great strength but also a capacity to withstand the destructive agents of the atmosphere.

Still it must be noted that the samples tested were perfectly solid, showing none of the irregular lamination observed in the larger beds. For this reason, one should not depend exclusively upon the laboratory tests in estimating the effects of alternate freezing and thawing on the stone as a whole.

Description of Individual Quarries.

THE C. & N. W. RY. CO.'S QUARRY.

The quarry of the C. & N. W. Ry. Co. has been operated almost continuously for about 40 years. It consists of a single opening about 400 ft. square and 19 feet deep. The company controls about 45 acres of land surrounding the opening, is equipped with all necessary machinery, and has an invested capital of about $21,000.00. For the past eighteen years the stone has been used almost exclusively for railroad purposes. Many of the bridge abutments on the C. & N. W. Railway, and the locks along the Fox river, between Green Bay and Wrightstown, are constructed out of this stone. It is now being used in the elevation of the tracks of the C. & N. W. Railway in Chicago.

Statistical Data.

Amount of capital invested: $21,000.00.

Facilities at hand for quarrying: 1 20-hp. engine; 1 channeler; 9 horse derricks; 8 steam drills; 2 boilers.

Average number of employees: 140.

Wages paid different classes of employees: Laborers, $1.25; quarrymen, $1.50; stone cutters, $3.00.

Cost of cutting and dressing: Bridge stone, $2.75 per cubic yard.

Shipment for the past five years: 1,000 to 2,500 carloads annually.

DUCK CREEK QUARRY.

The Duck Creek quarry, east of the railroad quarry, is owned and operated by M. Burnette. The quarry has been worked almost continuously for 43 years. It consists of one large opening about 17 ft. deep, and is equipped with all necessary machinery, including one polishing machine. The stone has found a market mainly in Milwaukee and the larger cities of the Fox River Valley, and has been used for bridges, piers, foundations, and heavy building purposes. Stone from this quarry has been used in the Milwaukee Post Office, Milwaukee City Hall, the Court House at Crystal Falls, Michigan, St. Joseph's Orphan Asylum at Green Bay, and in numerous other buildings.

Statistical Data.

Amount of capital invested: $1,000.00.

Shipments the past five years:

1892, bridge stone, 1,000 yds.; building, 1,000 yds.
1893, bridge stone, 1,500 yds.; building, 500 yds.
1894, bridge stone, 500 yds.; building, 300 yds.
1895, bridge stone, 300 yds.; building, 200 yds.
1895, bridge stone, 600 yds.; building, 400 yds.

Facilities at hand for quarrying: 2 engines, 3 steam drills, 1 channeler, 2 steam derricks, 4 hand derricks, 1 polisher.

Average number of employees: 6 to 25.

Wages paid different classes of employees: $1.25 to $3.00.

Cost of transportation: $.05 per 100 lbs. to Milwaukee, by rail.

THE GILLEN STONE CO.

The Gillen Stone Co.'s quarry was opened in 1891. It is located directly east of the Duck Creek quarry, and is operated by H. E. Gillen & J. A. Green. The quarry consists of one opening, 600 ft. long, 400 ft. wide, and 15 ft. deep. The company controls about 22 acres of land surrounding the opening, and is equipped with all necessary machinery, including steam pumps and steam drills. The market for the stone has been confined to a radius of about 100 or 200 miles. The stone has been furnished for basements, piers, buildings, and macadam. It has been used in the construction of bridges at Manitowoc, Sheboygan, Green Bay, and Neenah, and in bridges for the Wisconsin and Michigan railroads, and numerous buildings in Green Bay, Wis., and Menominee, Mich.

The samples tested in the preparation of this report were furnished by the Gillen Stone Co.

Statistical Data.

Amount of capital invested: $20,000.00.

Facilities at hand for quarrying: 4 engines and boilers, 1 steam derrick, 1 hp. and 1 hand derrick, 1 steam pump, 3 steam drills, 1 centrifugal pump.

Average number of employees: 30 to 40.

TRENTON LIMESTONE.

1. C. & N. W. Ry. Co.'s Quarry, Duck Creek, Wis. 2. Church, Oshkosh, Wis.

Wages paid different classes of employees:

Laborers	$1.50
Steam drillers	1.75
Helpers	1.25
Stone cutters	3.00
Foreman	2.25

Cost of cutting and dressing per square foot: From $.15 to $.50.

Ax-hammered	$.20
Bush hammered or chiseled	.35-.60

Average value of each grade per cubic foot: $.15 for rough stone.

General Considerations.

In general, the quarries of this area are prepared to furnish stone for all light or heavy constructional work. The stone which is taken from the three quarries is essentially the same, and the purposes for which it is suited are likewise the same. The main objection to the stone is the fine lamination which it possesses in nearly all of the beds of the quarries. The fine clay seams which are scarcely perceptible when the stone is first quarried often manifest themselves after years of exposure, resulting finally in shelling or flaking the stone. It is quite significant that the stone from these quarries which has been used in the bridge abutments of the C. & N. W. railroad, when once taken out cannot be built into the wall again, on account of its shelly condition. Before being placed in bridges or used in building foundations for heavy buildings, it should be carefully examined to see that no conspicuous parting planes are present. When the stone is used in positions where it is protected from the weather, the flaking will not be so likely to occur, and the carved and cut surfaces may remain for years as distinct as when the stone was first laid.

It is thought that the stone from these quarries has been used too generally in unfavorable positions, and that care should be exercised in its use. The reason that builders have considered the stone eminently fitted for constructional purposes is due mainly to the fact that the C. & N. W. Ry. Co. has used it so largely in the construction of heavy bridges along their line.

With this as a recommendation for the stone, it has been placed in many positions where its use may be questionable.

FOX RIVER VALLEY AREA.

The quarries included in this area are located at Kaukauna, Appleton, Neenah, Menasha, Oshkosh, and Waupun. Although subject to local textural variations, the stone does not differ materially from that quarried at Duck Creek. With the exception of that obtained at Kaukauna, the stone is mainly quarried either from the lower beds of the Galena or the upper beds of the Trenton. The Kaukauna limestone is not easily distinguished from the Duck Creek, and the general description of that stone will apply to that from Kaukauna also. The stone from the other localities varies in texture from that which is finely crystalline, to that which is coarse and sugary. The stone frequently contains small drusy cavities, partially filled with calcite and pyrite. The pyrite is differently colored, and varies considerably in crystal habit. Besides occurring in drusy cavities, it is sometimes disseminated through the mass of the rock in small crystals.

Small round, yellowish white spots of a quartzose nature occur in some parts of the limestone. When stone, containing such spots is placed in the wall of a building, the soft parts weather out, leaving cavities which look much like worm borings. These imperfections in the stone are often obscured by hammer dressing, but this method of obliterating the true character of the stone is only temporary, and after a number of years of exposure to the atmosphere the imperfections often show again.

Quarries at Kaukauna.

LINDAUER'S QUARRY.

As previously noted, the stone quarried near Kaukauna is very similar to that obtained from Duck Creek. It is quarried mainly by L. Lindauer, along the bed of the Fox river, between Kaukauna and Little Chute. The river channel at this place is shallow, and during high water the river spreads over

the adjacent land, forming a narrow flood plain. When the water is low, the limestone is exposed in the channel, and it is mainly from these exposed beds that the stone is quarried. The beds are 8, 12, and 19 inches in thickness, and stone can be obtained in almost any required lateral dimensions. The stone is irregularly laminated, similar to that from the Duck Creek quarries, and is broken by vertical joints which strike N. 33° E. and N. 40° W.

It has been noticed by the workmen that the stone which is taken from the river bed at the lowest level is more solid than that which is taken higher up. This is simply an indication that the stone which is ordinarily beneath the water has not been subjected to alternate freezing and thawing, as has the stone which occurs at or above the water level. The sap is often several inches deep, necessitating capping the stone when used in important positions. The beds are not perfectly horizontal, on account of which one part may be under water, while another is above. For this reason, a single bed may be shelly in one part and solid a short distance away. Occasionally a small clay pocket occurs in certain of the beds, but such an occurrence is not common.

A number of buildings have been constructed out of this stone, among which are several of the pulp and paper mills at Kaukauna. One of these mills was burned in 1896, but the walls still stand, and with one exception they will probably be used in the reconstruction of the building. As a result of the fire, the stone flaked off on the corners, where the heat was most intense.

BLACK'S QUARRY.

A small quarry, owned by Mr. Black, is located about a half a mile north of the city quarry. The different beds are very similar to those in the previously described quarry. The opening has a depth of about 8 ft., and is about 200 ft. square. Blasting is the principal method employed in quarrying, and for this reason much of the stone has been shattered and broken.

This quarry is away from the river, and the stone can be bet-

ter depended upon than that which is quarried from the river bed.

The stone from these quarries is suited mainly for those uses in which the danger from freezing and thawing are a minimum. Where it is used for walls or trimming, care should be exercised in selecting that which is perfectly sound.

Quarries at Appleton.

GRAND CHUTE STONE QUARRY.

Stone, similar to that obtained at Kaukauna, is quarried indiscriminately from the bed of the Fox river at Appleton. Stone is also quarried by C. F. Smith, at a place about three miles south of Appleton. This quarry, known as the Grand Chute Stone Quarry, consists of one opening about 150 ft. long, 100 ft. wide, and 19 ft. deep. The quarry was opened in 1893, and has been worked almost continuously each year since.

The bedding planes are rough and irregular, splitting the stone into layers from 6 to 12 inches in thickness. The jointing planes strike N. 40° E. and N. 47° W., and are from 4 to 10 feet apart. An occasional mud seam penetrates the quarries to a depth of 6 or 8 ft., injuring the adjacent stone. The stone has a somewhat coarse, sugary texture, and breaks with a splintery fracture. The predominant color is dark bluish gray, with occasionally a pinkish tone. The stone which is quarried for coursing is rough, and, unless hammer dressed, has a somewhat unsatisfactory appearance.

TESCH'S QUARRY.

Another small quarry, which is located about half a mile northwest of the Grand Chute quarry, is owned and operated by August Tesch. The stone is essentially the same as that taken from Mr. Smith's quarry. The face is about 6 ft. deep, below which is a bed of soft sand rock, in which are imbedded numerous geodes of marcastite.

Quarries at Neenah and Menasha.

The demand for rough foundation stone and trimmings in these cities is supplied mainly by quarries located in the imme-

diate vicinity. The quarries are five in number, and are owned and operated by W. H. Jones, Jens Jorgenson, Robt. Felker, Phillip Abendshein, and Fred Engel. The stone is essentially the same as that which has been described from the Grand Chute Stone Quarry of Appleton.

ISLAND CITY QUARRY.

The quarry which is owned and operated by G. C. Jones, of Neenah, is located on what is known as the island, from which it derives its name. The opening is small, being about 200 ft. long, 350 ft. wide, and 5 ft. 10 in. deep. The stripping is very light, and the beds are from 4 to 20 inches thick. The stone is a dark blue, dolomitic limestone. It dresses quite readily, but on acount of its laminated structure, is little suited for fine building purposes. It is used mainly for foundation and curbing.

THE MENASHA QUARRY.

This quarry is located immediately north of Menasha, on the Menasha and Appleton road, and is owned and operated by Jens Jorgensen. It has a face of about 32 ft., of which 2 to 5 ft. are stripping. The best coursing stone occurs at a depth of about 4 ft. 6 in., and is from 8 to 9 in. thick. The beds dip at an angle of about 8° SW. The stone from this quarry is used largely for macadam, although foundation, curbing and ordinary building stone are also sold.

Statistical Data.

Amount of capital invested: $3,000.00.

Facilities at hand for quarrying: 2-12 hp. engines; 1 steam drill; 1 steam pump.

Average number of employees: From 5 to 30.

Wages paid different classes of employees: Foreman, $2.00; engineers, $1.75; teams, $3.00; labor, $1.25.

NEENAH STONE QUARRY.

This quarry, which is owned and operated by Phillip Abendshein, is located on the lake shore road, near the southern limits of the city of Neenah. The quarry was opened about 25 years

ago, and has been operated each year since. One opening, about 8 ft. deep, has been made, from which stone 10 in. or less in thickness and of almost any desired lateral dimensions can be quarried. The stone is similar in all respects to that from the other quarries in this vicinity, and is used mainly for foundation purposes.

Statistical Data.

Amount of capital invested: $6,000.00.
Equipment: 1 steam crusher, crowbars, drills, etc.
Average number of employees: 6.
Wages paid different classes of employees: $1.25 to $2.00.
Average value of each grade per cubic foot; About $.03.

THE OLD M'GRAW QUARRY.

This quarry, owned by Fred Engel, was opened in 1862, and has been worked each year since. It is situated about a mile from Neenah, and consists of a single opening about 400 ft. long 400 ft. wide, and 6 ft. deep. The beds are from 4 to 12 inches in thickness, and are cut by vertical joints striking N. 82° E. and N. 42° W. The stone is very similar to the Trenton limestone quarried elsewhere, except that the color has a purplish tone. The stone has been used exclusively for local consumption, and may be seen in the Second and Third Ward Schools and the German Lutheran church at Neenah, and the new German Lutheran church at Menasha.

Statistical Data.

Amount of capital invested: $2,000.00.
Facilities at hand for quarrying: Everything done by hand.
Average number of employees: 4.
Wages paid different classes of employees: $1.50.
Cost of cutting and dressing stone per square foot: $.25.
Average value per cubic foot: $.04 and $.06.

FELKER'S QUARRY.

A short distance from the quarry owned by Phillip Abendshein is located the quarry operated by Robt. Felker. The face

of the quarry is about 9 ft. deep. The beds run from 7 to 11 inches in thickness, and are cut by irregular joints which strike N. 35° W. and N. 85° W. The stone has a dark blue color, and is rough and irregularly bedded, often containing small drusy cavities, lined with calcite.

Quarries at Oshkosh.

Like the other quarries of the Fox River Valley area, those in the vicinity of Oshkosh have been developed mainly to supply the local demand. Very little of the stone is shipped out of the city. Three quarries are located at this place, owned and operated respectively by Lutz Bros., Last & Son, and Wm. Riek. These quarries are all located near the outskirts of the city, in what is known as South Oshkosh.

Lutz Bros.' quarry illustrates the general character of the stone from all three of the quarries. The main joints strike N. 38° E., N. 83° E., N. 38° W., and N. 70° W. The first set, occurring at intervals of 20 ft., is the main set. The others are more irregular, and often much closer. The following vertical section of this quarry indicates the general character of the beds.

10 ft. Stripping.
7 ft. Series of beds from 3 to 8 inches in thickness.
8 in. Solid bed. Used for dimension stone.
1 ft. Can be split into two beds in many places. Used for curbing.
3 in. Flagging.
16 in. Used for dimension stone.
9 in. Used for flagging.
11 in. Used for curbing.
9 in. Used for dimension stone.
2 in. Flagging.
4 in. Flagging.
4 in. Flagging.
2 ft. Composed of seven flags, 2 to 4 in. in thickness.
4 in. Flagging.
7 in. Used for various purposes.
7 in. Used for various purposes.
2 ft. 10 in. Very irregularly laminated. Used for foundation purposes.
5 in. Used for curbing.
5 in. Used for curbing.

The bedding planes are frequently discontinuous, on account of which an apparently massive bed, in one part of the quarry, may break into two or three smaller beds in another part. The color is blue to bluish gray. The heavier beds are somewhat vesicular, frequently exhibiting small drusy cavities, partially filled with crystals of calcite or pyrite. Fossils are found abundantly between the beds.

A number of buildings have been constructed out of stone from this quarry, some of which have stood as many as 15 or 20 years. The stone in the walls of the older buildings shows the effect of exposure to the atmosphere. In some places the stone appears as though it had been permeated with worm borings. The appearance of the stone in the lately constructed buildings is very good when viewed from a distance, but when closely examined, the stone presents a somewhat rough surface, in which drusy cavities, lined with pyrite and calcite, are conspicuous. The stone is used both for rock face and hammer dressed work. The principal uses are building, foundations, and curbing.

The stone which is quarried from Last & Sons' and Reick's quarries does not differ essentially from that which is quarried from Lutz Bros.' quarry.

Quarries at Waupun.

Several quarries have been opened in the Trenton limestone at Waupun, the output being used almsot entirely for local consumption. Among the quarries which have been lately operated may be mentioned those of S. M. Randall, John McCuen, and John S. Lee. The stone from these quarries does not differ materially from the Trenton limestone quarried in other parts of the Fox River Valley.

THE WAUPUN STONE QUARRY.

The Waupun Stone Quarry, which is owned and operated by S. M. Randall, was opened about 25 or 30 years ago. It consists of one opening about 250 ft. long, 130 ft. wide, and 12 ft. deep. The stone occurs in beds from 4 to 12 inches in thickness, and can be quarried in blocks of any reasonable lateral di-

mensions. The following is a section of the quarry beginning at the top.

5 ft. 8 in. Used for foundation stone. Occasionally a piece is obtained which is suitable for coursing. The stone has a brownish color, which has resulted from weathering.

4 in. Flagging.

9 in. Used mainly for coursing. The sap is about 1¼ inches deep.

7 in. These beds are comparatively free from drusy cavities. The stone is used mainly for sills and caps.

5 in. Very vesicular and spotted with brown. Suitable only for the roughest foundation or footing work.

5 in. Coursing.

3 in. Rubble for foundation stone.

7 in. Coursing. This bed is comparatively solid and even textured.

11 in. Coursing. Is dressed for corners. This layer sometimes splits into two beds.

2 ft. Not well exposed. Used for foundation purposes.

The stone from this quarry has been used in the construction of the water works tower, in several stores in the city, in the State Prison foundation, in the Brandon High School, and in a large number of other equally important structures.

Statistical Data.

Amount of capital invested: $1,000.00.

Facilities at hand for quarrying: Steam drill; 1 engine, 10-hp; stone crusher; hammers, wedges, bars, etc.

Average number of employees: From 6 to 20.

Wages paid different classes of employees; $1.25 to $1.75.

Shipments during the past five years: 75 cords coursing stone; 150 cords flagging; 1,200 ft. window sills and caps.

LEE'S QUARRY.

The quarry owned and operated by John S. Lee is located in the northeastern part of the city of Waupun. It was opened in 1857, and has been operated more or less each year since. The opening covers about 1½ acres of ground, and is about 10 ft. deep. The beds are from 3 to 8 in. thick, and can be quarried in large lateral dimensions. The face of the quarry consists of about 13 or 14 courses of stone, all of which is used for

foundation purposes. The stone from this quarry has been used in the Odd Fellows Hall, State Prison, and numerous other buildings in Waupun.

THE M'CUEN QUARRY.

The McCuen quarry is immediately adjacent to the Lee quarry, just described. The opening is irregular in shape and has a depth of about 8 ft. The face consists of twenty beds of stone, from 4 to 8 inches in thickness. The bedding planes are irregular and the floor is somewhat uneven. The color of the stone is ordinarily blue, but, due to weathering, it frequently has a yellowish color. Some of the rock is stained brown, which is probably due to the weathering of pyrite. The joints strike N. 75° W., N. 40° E., and N. 40° W. They occur at sufficient intervals to allow reasonable dimensions to be quarried, and still they are close enough to aid materially in quarrying.

General Considerations.

It is evident from the examination of the quarries of the Fox River Valley, that the stone quarried is mainly suitable for foundation and footing purposes. It is ordinarily difficult to dress, and has a rather somber appearance when worked into buildings. The small drusy cavities, and the irregular lamination, which is marked by thin leaves of clay, occurring in some of the stone, renders it undesirable for fine constructional work. Yet in spite of this, if the stone is carefully selected, it can be used to advantage for brick trimming, coursing, and other similar purposes.

THE SOUTHERN AREA.

The southern area of Trenton limestone includes the quarries at Beloit, Afton, and Janesville. The product of the quarries at these places is used almost entirely for local purposes, and mainly for foundation work and brick trimmings. In some places the stone has been manufactured into lime, and in others it has been crushed for macadam.

Quarries at Beloit.

The two most important quarries at Beloit are owned and operated by Mr. Merrill and Wm. Samp.

SAMP'S QUARRY.

Samp's quarry, which is located near the northern outskirts of the city, consists of one large opening, which has a face of about 25 ft. The color of the stone is mainly buff, although a number of the lower beds are blue. The thickness of the beds is somewhat irregular, some of them being badly broken up. The joints strike N. 85° E. and N. 30° W. The stone can be quarried in almost any dimensions, pieces 13 ft. long having been obtained. The beds which are most generally used for coursing are 9 in. thick and have a buff color.

MERRILL'S QUARRY.

The quarry owned and operated by Merrill is located two miles west of the city, and to all appearances has not been operated for a number of years. The stone has a buff color, and the beds, which are from 4 to 6 inches thick, are much broken up. The quarry has a face of about 20 ft., and the joints strike about N. 80° W. and N. 85° E. The stone is suitable for rough foundation work.

General Considerations.

Several of the larger churches, dwelling houses, college buildings, and business blocks have been partially constructed out of this limestone. In all these instances the stone shows more or less deterioration from weathering. As in the case of many of the stone buildings constructed thirty or forty years ago in this part of the country, the joints between the blocks of stone are wide and irregular in shape. The mortar naturally weathers more rapidly than the stone, and if the joints are large the decay of the wall is hastened accordingly.

Certain of the older houses in Beloit are built of cobble stones,

cemented in layers with mortar. The walls are often unique and artistic in design, but necessarily not very durable.

Quarries at Janesville.

The Trenton limestone has been much more extensively exploited in the vicinity of Janesville, than in the vicinity of Beloit. Five quarries are now operated. They are owned by J. C. Miltemore, C. Stout, Andrew Barron, Mr. Risling, and Mr. Pratt. All the stone from these quarries has essentially the same characteristics. The color is ordinarily buff, with an occasional course in which the core is blue.

THE EUREKA QUARRY.

The Eureka quarry, which is owned by J. C. Miltemore, is located in the south part of the city, near the tracks of the C. & N. W. Railway. The upper thirty feet of the quarry consists of thinly bedded limestone, much broken up. This stone is crushed and used for macadam. The next 8 ft. 6 in., in which the stone ocurs in beds of irregular thickness, much broken up, is used mainly for foundation purposes. Below this for 12 ft. the beds are heavier, and larger dimensions can be quarried. Immediately below these heavier beds of limestone, and resting on the St. Peters sandstone, are two 18 in. beds of calcareous sandstone. These two quartzose beds are thought to be better adapted to withstand weathering than any of the upper courses, and for this reason they are used in positions near the water line.

Statistical Data.

Amount of capital invested: $20,000.00.

Average number of employees: 6-15.

Wages paid different classes of employees: $1.50.

Cost of transportation: By wagon $1.50 per cd.

Average value per cord: $3.00 per cd. in quarry.

Shipments for the past five years:

1892	2,000 cds.
1893	2,000 cds.
1894	2,000 cds.
1895	1,333 cds.
1896	1,333 cds.

STOUT'S QUARRY.

The quarry which has been owned and operated by C. Stout is located near the southern limits of the city, on the west side of the river. Some of the beds are as much as 3 ft. in thickness, but these may be split into thinner courses, if desired. Wavy lamination is characteristic of the stone, and thin beds of clay are found between the strata. The top layers in the quarry are covered with about 5 ft. of gravel, which constitutes the maximum dead stripping. The upper 15 ft. of stone is thinly bedded and much broken up, being unsuited for constructional purposes. The 10 ft. below these thin layers are more heavily bedded, and are used for foundation and footing purposes.

BARRON'S QUARRY.

The quarry owned and operated by Andrew Barron is located southwest of Janesville, just outside of the city limits. The quarry has not been operated for a number of years, but the stone is essentially the same as that taken from the other quarries.

Statistical Data.

Amount of capital invested: $6,000.00.
Average number of employees: 12.
Wages paid different classes of employees: $1.00 to $1.75.
Cost of transportation: by water, $2.00 to $3.00 per cd.
Average value of each grade: Rubble, $3.00 per cd. in quarry.
Dimension, $3.50 per cu. yd.

RIEK'S QUARRY.

The quarry which is operated by Wm. Riek is located about 1½ miles north of the city and close to the river. Both the buff and blue limestones are quarried from this opening. The lower five feet of the buff beds are solid and apparently of good quality. The lowest beds in the quarry are blue, and are from 12 to 13 inches thick. The face of the quarry is about 45 ft. deep, and has a dead stripping of from 20–25 ft., most of which is

thinly bedded, much broken up limestone. The upper 5 or 6 ft. are sand and gravel.

The jointing and bedding are brought out clearly by weathering, and show that large dimensions can be quarried from the blue beds. The stone has been used mainly for bridge abutments, arches, and foundations.

PRATT'S QUARRY.

Located a short distance south of the last described quarry is another, owned and operated by Mr. Pratt. The beds have essentially the same characteristics as those occurring in Riek's quarry. The face of the quarry is about 30 ft. deep. The stripping is heavy, a large part of the stone at the top being thinly bedded and much broken up.

Quarry at Afton.

A single quarry, owned and operated by Owen E. Gower, is located at Afton. The quarry is across the river, immediately south of the village, and consists of a small opening about 12 ft. deep and 60 ft. long. The stone which is quarried comes from the Trenton beds immediately above the St. Peters sandstone, and is suitable only for foundation purposes.

THE SOUTHWESTERN AREA.

The Southwestern area includes a large number of quarries, located at different places in the southern and western parts of the state. Among the principal localities may be mentioned Mineral Point, Monroe, Darlington, Platteville, Cassville, River Falls, and Watertown. The general characteristics of the stone, and the similarity in occurrence to that of the other areas make it unnecessary to go into details with reference to the individual quarries.

Quarries at Mineral Point.

The most important quarry in the Trenton formation at Mineral Point is the public quarry. This quarry is situated about

a mile south of the city, and consists of a single opening, immediately adjacent to the wagon road. The upper courses, and portions of the lower, near the hillside, have a uniform buff color. Deeper in the quarry the layers are less altered, and have a large or small core of blue. Along the jointing planes, alteration has everywhere extended to a considerable depth. It is claimed by the quarrymen that the buff beds are easier worked and withstand the weather better than the blue. The joints in this quarry strike about N. 63° E., N. 10° W., and east and west. The jointing planes break the rock into various sized dimensions, sufficiently large for all ordinary uses.

Quarries at Darlington.

In the vicinity of Darlington the quarries in the Trenton formation are more abundant than at Mineral Point. This is probably due to the absence of suitable sandstone, such as has been used quite largely at the latter place. The quarries in the vicinity of Darlington are operated by N. J. Thompson, Olaf Berglund, Harry Cone, and Thomas Fawcett.

A number of houses and business blocks in Darlington have been erected out of stone from the various quarries. The masonry work is rough, and the appearance of the buildings correspondingly uninviting.

THOMPSON'S QUARRY.

The quarry which is owned and operated by N. J. Thompson is known as the Darlington Hydraulic Cement Quarry. It is located about 3 miles southeast of the city, was opened in 1893, and has been operated each year since. The opening is about 120 ft. long, 80 ft. wide, and 30 ft. deep. Dimension blocks from 4 in. to 4 ft. thick, and 10 ft. square can be readily quarried. The stone has been furnished for foundation and wall purposes, but the main product of the quarry has been lime and cement.

The following analysis of this limestone, made by H. L. Bowker, State Assayer of Massachusetts, shows its chemical com-

position. In one hundred parts by weight, there are the following proportions:

Silica	21.50
Oxide of iron and aluminum	30.50
Carbonate of lime	24.57
Carbonate of magnesium	23.43
Total	100.00

FAWCETT'S QUARRY.

The quarry owned and operated by Thomas Fawcett is immediately south of the Pecatonica river in the city of Darlington. The following section, taken from this quarry, indicates the general character of the stone from the entire area:

3 ft.	Stripping.
18 to 20 ft.	Very vesicular. Buff to yellowish brown color. Beds from 1 2½ ft. thick. Thin leaves of shale between the beds.
6 ft.	Thinly bedded and much broken up.
12 ft.	Thinly bedded and badly broken. Used mainly for manufacturing lime.
24 ft.	Upper 6 ft. much broken up. The remaining beds are but little weathered, and have the original blue color.

The walls of the jointing planes, which strike N. 25° E. and N. 65° W., are heavily incrusted with calcite. The joints are very regular and run from 10 to 20 ft. apart. The beds can be quarried from the lower courses, in thickness ranging from 1 to 3 feet.

CONE AND BERGLUND QUARRIES.

The quarry of Olaf Berglund is south of the city, and that of Harry Cone is east of the city. The stone from each of these quarries is essentially the same as that from the above described quarry.

Quarries at Platteville.

The supply of stone for building and other purposes in Platteville has come mainly from local quarries in the Trenton limestone. The principal quarries are owned by Peter Helker, Wm. Place, and the city.

HELKER'S QUARRY.

The quarry, which is owned by Peter Helker, is located about three miles southwest of the city. The following is a vertical section of the quarry from the top to the bottom:

2-5 ft.	Stripping.
2 ft.	Rip-rap.
2 ft. 4 in.	Three 7-inch courses used for building stone.
2 ft.	Can be capped into two courses. Used for building.
3 ft. 2 ft. 2 ft. 10 in.	Each of these beds can be capped, but they are very tight when quarried some distance back from the face. Used for building.
1 ft. 3 in. 11 in. 10 in. 1 ft. 2 in.	These courses are the same as above.

The stone has a decidedly buff color, showing only occasional small cores of blue. Occasional brown stainings of iron oxide indicate the former presence of marcasite or pyrite. Mud seams occur in the quarry. The joints are well defined and strike north and south, and N. 83° W. They occur from 6 to 10 feet apart. The stone is used for foundations, sills, steps, etc.

About 80 rods east of this quarry the "glass rock," which is the lowest bed of the Galena, outcrops near the summit of the ridge. This "glass rock," as the dense limestone is called, has been quarried at this place to furnish stone for the construction of the Normal School Building at Platteville. The blocks used are small, and out of all proportion to the size of the building. The stone is very brittle, and breaks with a splintery fracture, occasioning considerable difficulty in cutting and dressing. This, combined with the small size of the blocks, does not recommend it as a building stone.

CITY AND PLACE'S QUARRIES.

The City quarry is about a mile and a half north of the city, and the quarry owned by Wm. Place is directly across the road. The color of most of the stone in these quarries is blue, although some of the beds have been partly altered to buff. Irregular lamination, marked by thin layers of clay, is everywhere noticeable in the blue beds. Stone, from 1½ to 2 ft. in thickness, can be

readily obtained. Some of the beds are very fossiliferous, and the jointing planes, which strike N. 30° W. and N. 72° E., have been partially filled with calcite incrustations.

Quarry at Cassville.

The main quarry at Cassville, owned and operated by John Ortscheid, is located on the side of the bluff directly east of the city. The upper part of the bluff is Galena limestone, while the blue and buff beds near the base are in the lower subdivision of the Trenton. The stone is quarried mainly for foundations, sidewalks, and cross-walks.

Quarries at River Falls.

At River Falls, in Pierce county, the demand for building and foundation stone is largely supplied by two quarries, owned by Thos. Walker and George Currier. The stone is quarried from the lowest beds of the Trenton, which cap the bluffs of St. Peters sandstone, east of the city.

The two quarries join each other on the same bluff. The uppermost beds are badly broken up and worthless. The five lowest beds, from 6 to 12 inches in thickness, are quarried for dimension stone. The quarrying is facilitated by the presence of well defined joints, which split the rock into dimensions that are readily handled. The strike of the joints is about N. 5° E., N. 68° E., and N. 55° W.

The stone is used in retaining walls, steps, hitching posts, and buildings. The back and side walls of many of the business blocks are constructed out of rough stone from these quarries, but the fronts are usually built of brick.

Quarry at Watertown.

At Watertown the local demand for foundation stone is supplied by Tetzlaff & Co., who own and operate a quarry in the Trenton limestone about 2½ miles north of the city. The quarry was opened fifty years ago, and the stone is used mainly for the manufacture of quicklime. The stone is rough, but is nevertheless sold for foundation purposes.

Statistical Data.

Amount of capital invested: $10,000.00.

Average number of employees: 8.

Wages paid different classes of employees: Day laborers, $1.25.

Average value per cord: $8.00.

Shipments for the past five years: 1896, 130 cds. for building and foundation purposes.

RÉSUMÉ.

The limestone of the Trenton formation is quite readily quarried. It occurs in beds of different thicknesses, which vary greatly with the depth at which they are quarried. The beds are broken into dimensions of reasonable size by two and occasionally three sets of joints, intersecting each other at different angles. The manner of occurrence of the stone, combined with the large local demand in the Trenton limestone region, accounts in a measure for the large quantities of stone exploited from the many quarries of this region. The present inactivity has been occasioned by the introduction of a higher grade of stone and the increased consumption of brick.

The stone throughout the entire formation has the same general characteristics. From certain horizons the stone dresses nicely, and has a pleasing bluish gray color. In other parts, local textural differences enter, which injure very materially the appearance and value of the stone.

For supplying the local demands for common stone, this formation constitutes a very important source. The stone is suited mainly for foundations, footing, and the rougher kinds of masonry construction, but certain beds work very nicely into sills, steps, hitching blocks, etc. Some of the stone is also used very acceptably for back walls, sidewalks, and cross-walks. One caution should be observed, and that is to avoid using the stone where there is danger of saturation with water at the time of alternate freezing and thawing. The weather has a tendency to open up the irregular laminæ which are so conspicuous in many of the beds of this formation. The stone which is placed at or near the water line suffers the greatest injury. In the walls above the water table the injury from weathering is less marked.

CHAPTER VI.

LIMESTONE (continued).

THE NIAGARA FORMATION.

The Niagara limestone occurs in a broad belt extending from the northern part of Door county south to the state line, a distance of about 200 miles. The formation has a maximum width of about 40 miles, and extends from Lake Michigan on the east to the Fox River Valley on the west. Owing to marked differences in texture, this formation has been divided into several different subdivisions, known as the Guelph, Racine, Waukesha, Byron, Mayville, Upper Coral, and Lower Coral beds. In this report no attempt will be made to distinguish between these different subdivisions, but the formation will be treated as a whole. This formation has furnished stone not only for building and road construction, but also for the manufacture of lime, for the production of which it is unexcelled. From the north to the south, throughout all parts of the formation, quarrying has been more or less extensively engaged in.

The Niagara limestone rests directly upon the beds of Clinton iron ore, and is only concealed in a few places by the Lower Helderberg limestone and the Hamilton Cement rock. The limestone differs very essentially in texture and manner of occurrence from that of either of the two limestone formations previously described. The composition is nearly that of a dolomite, although in some instances the percentage of magnesium carbonate is relatively small. The texture, hardness, color, and bedding differ widely in different parts of the formation.

In the following description only those quarries from which

stone is exploited for constructional purposes are considered, no attempt being made to describe in detail the quarries that are interested solely in the manufacture of quicklime.

Description of Individual Areas.

In the following descriptions each of the different areas is considered separately, and local differences in the stone from different quarries are noted under the treatment of the individual quarries. The following is a list of the more important areas and quarries in the Niagara limestone formation, from which stone is exploited for constructional purposes.[1]

Wauwatosa—Story Bros., A. F. & L. Manigold, Monarch Stone Co.

Waukesha—Waukesha Stone Co., Hatfield Co.

Genesee—Genesee Quarry Co., Lee Bros. Quarry.

North Prairie—Wm. Zunker.

Lannon—Williams & Lannon, Blair & Larson, Davis Bros., J. H. Walsh, Frank Wallen, Harmon & Sons, Kiefer & Flannagan, Menominee Falls Quarry Co., Sheridan Bros.

Racine—Horlick Lime & Stone Co., Fox's Lime & Stone Co., John O'Laughlin.

Burlington—W. A. Aldrich.

Pewaukee—C. A. Cairncross, Caldwell & Nelson.

Templeton—J. H. Carney, Rich Forrestall, Hummel & Elliott, Bentley, Lund & Co.

Cedarburg—John Groth.

Grafton—The Mace Co., Anshuetz Co.

Port Washington—Dricker Co.

Grimms—The Cook & Brown Lime Co.

Brillion—Ormsby Lime Co.

Mayville—O. S. Cochran, Henry Rudebusch.

Knowles—Happe Bros., Frank S. Bauer.

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[1]This list does not include all quarries in the Niagara limestone formation but is supposed to comprise all from which stone is quarried for shipment, as well as a number of the more important from which stone is quarried simply to supply the local demand.

Marblehead—Geiger's Quarry, Marblehead Lime & Stone Co., Nast Bros.

Hamilton—Hamilton Lime & Stone Co., Seth Slyvester's Quarry, Thos. Costello.

Sheboygan—Sheboygan Lime Works.

Sheboygan Falls—Henry Kohlhagen.

Kewaunee—John Borgman.

Peebles—C. & N. W. Ry. Co.

Sturgeon Bay—Laurie Stone Co., Washington Stone Co., Latham Smith, Frank Hagen.

WAUWATOSA AREA.

The Wauwatosa quarries are situated immediately west of Milwaukee and adjacent to the C., M. & St. P. Ry. (See Plate XL.) The quarries are three in number, and are controlled by as many different firms. The first quarry opened was that of Story Bros., about the year 1855. The two quarries opened since that time are owned and operated by the Monarch Stone Co. and A. F. & L. Manigold. The company, known as the Wauwatosa Stone Co., is a combination of the three companies, made to regulate the sale of the stone in Milwaukee county. All the stone which is contracted for in this county from these quarries is sold by the Wauwatosa Stone Co.

Quarry Observations.

The three quarries are located in close proximity to one another, and all draw their supply from practically the same beds. The stone is distinctly bedded, and separated into layers, ranging from 4 to 28 inches in thickness. The major vertical joints strike N. 56° W. and N. 50° E. They are from 4 to 20 feet apart and permit stone of large dimenions to be readily quarried The bedding planes are in some places smooth, while in others they are rough and irregular. An occasional poor streak occurs in the quarries, which runs in a SE. and NW. direction. The floors of the different openings are not perfectly even, but dip in some places to the north and in others to the south. Faulting

along the jointing planes in two directions occurs in several places. The throw of these faults, as measured in Story Bros. quarry, is about 2 or 3 inches. The joints along which the major faulting occurs strike N. 50° E. The other set strikes N. 70° E.

The color of the stone is the same in all the quarries, but differs between the various beds. The color of certain of the beds is almost white, others have a delicate buff color, but the predominant color is light gray. Certain beds are peculiarly mottled with light pink, which is attributed to the weathering of an occasional crystal of iron pyrites. Along the more prominent jointing planes, to a depth of from 6 to 18 inches, the rock has a quite uniformly yellowish tint. Certain of the layers contain very fine black spots, which give the rock, when looked at closely, a speckled appearance. These spots are more conspicuous in the pink than in the gray or cream colored parts. They are supposed to be due to minute particles of iron oxide, resulting from the weathering of pyrite.

Two distinctly different textured limestones are taken from these quarries. The first and most abundant is a finely crystalline compact limestone, generally free from incipient joints or stratification planes. The second is a rock with a coarse granular texture, which often occurs in heavy beds, several feet in thickness. Certain small layers in the quarries are shelly, and are crushed for macadam. The stone from the different beds of fine textured limestone differs in the readiness with which it works under the hammer. The beds which are soft work with comparative ease, but those which are more densely compacted sometimes work with considerable difficulty.

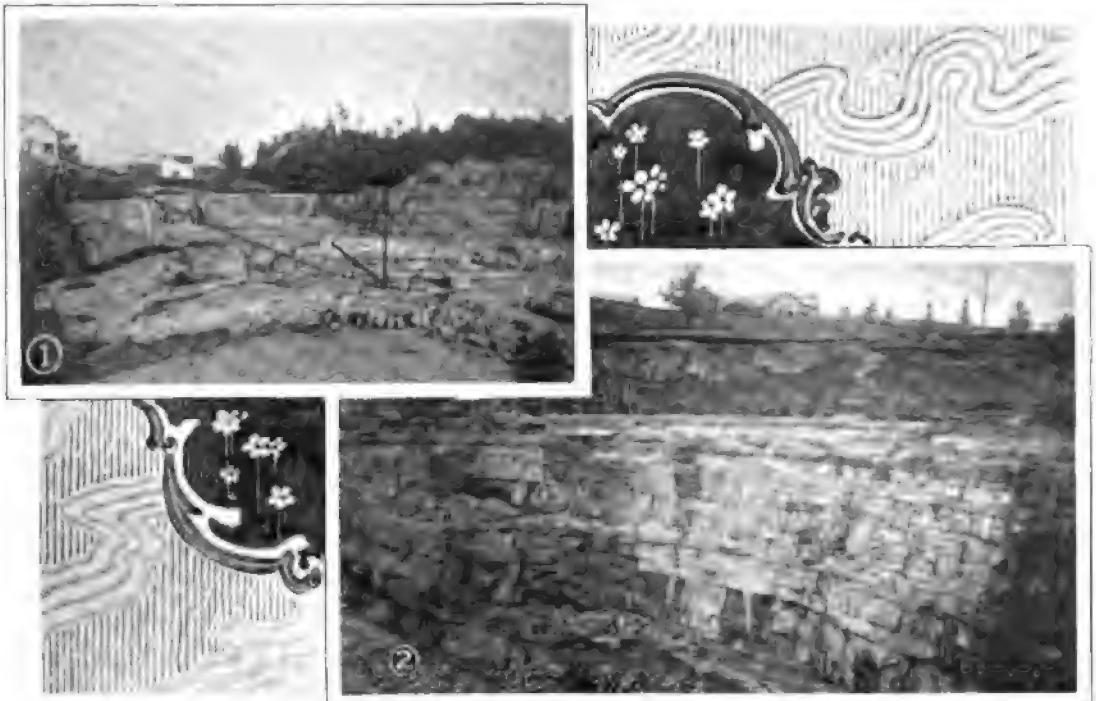
The stone from these quarries is sold as footing, rubble, ashlar, sills, and paving. Each of the quarries consists of a single opening over 50 feet deep and of large lateral dimensions. The following vertical section, taken from Story Bros.' quarry, gives an excellent general idea of the different courses of stone which may be obtained from any one of the three quarries, and the purposes for which it is being used.

5–20 ft.	Stripping.
9 in. 22 in.	These two courses and the two immediately below have not yet been worked. They are granulated, and will be used as footing stone.
10 in. 15 in.	Fine textured, probably serve as building stone.
6 in. 4 in.	These beds are somewhat coarse and rough, being used for footing.
14 in.	This course is used for footing and rubble. Portions of it contain drusy cavities filled with calcite.
5 in.	Footing.
12 in.	Footing. Sometimes splits into two 6 inch beds.
7 in. 7 in. 7 in. 7 in.	These beds are somewhat rough. They are not strictly granulated but have a mixed texture. Used for footing.
5 in.	Light brick footing.
11 in.	Smooth, even textured course. Used for dimension stone.
4 in.	Brick footing.
20 ft.	Fine, even textured course. Sometimes used for pier work. Suitable for dimension stone.
7 in. 8 in. 11 in.	Rough, granulated beds, used for footing.
9½ in.	Rough stone, used for footing.
13 in. 8 in. 8 in. 7 in.	Even textured courses. Used for rough hammer dressed pier work.
2 in.	Flagging.
8 in.	Footing course. Somewhat rough.
8 in. 12 in.	Rough granulated courses, used for footing.
11 in.	Even textured course. Uniform color. Used for fine dressed work.
6 in.	Smooth, fine textured course. Used for sills.
16 in.	Granulated course. Used for heavy footing.
9 in. 8 in. 7 in. 8 in. 10 in. 11 in.	These beds are rough and partly granulated, being mixed courses, used mainly for footing purposes.
21 in 12 in. 13 in.	These courses are used for dressed stone for dimension purposes.
9 in. 8 in.	Footing courses.
11 in.	This course is uniform in color and texture, and is used for fine dressed work.

12 in.	Used for dressed work.
6 in.	Footing course.
16 in.	Half of this course is granulated and half is solid. This bed is used for heavy foundation work.
8 in. 9 in.	Used both for footing and dressed stone.
15 in.	Sometimes dressed, but not easily worked.
12 in.	Used for piers.
18 in.	This course is rather hard, but is used for pier work.
26 in. 16 in. 15¼ in. 13 in.	These courses are used for fine dimension work. The color is mainly white, but is mottled with pink as described on a previous page. The black specks are not conspicuous in these courses. The rock is soft and fine grained, and is the best stone in the quarry for bush hammer work.
17 in.	Fine compact stone. The Loan & Trust building in Milwaukee was built mainly out of stone from this course.
5 in. 10 in. 4 in.	Partially granulated, used for footing and rubble.
22 in.	Used for rough foundation work and piers. This bed runs out in one part of the quarry until it is only 5 in. in thickness. At this place it is shaly and unsuited to any work. By the quarrymen it is said to pinch out.
21 in.	This bed can be split into 10 and 11 inch courses. The stone has a fine texture and uniform color, somewhat darker than that which occurs in the courses above. It is used for dimension stone.
10 in.	Dimension stone.
19 in.	This bed splits into 9 and 10 inch courses, or can be quarried solid. Used for dimension stone.
15 in.	Dimension stone, used for piers, tables, etc. The stone has a bluish tone.
14 in.	This is the third floor. The bed is split into 10 inch and 4 inch courses. It is somewhat granulated and is used for footing.
15 in.	Used for footing and rubble. Some pyrites was observed along the seams at this depth.
20 in.	This course is used for fine dressed work, but is not quite as desirable as that in other parts of the quarry.
4 in.	Flagging or curbing.
21 in.	Fine textured, uniformly colored course. Used for bases, piers, steps, and other fine cut work. The stone is solid and easily dressed. It has a cream color when seasoned.
9 in.	Used for water tables, footing, and dressed work. This course is much freer from stains than some of the courses deeper in the quarry.

6 in.	Used for sills.
12 in.	Used for fine rock faced work. Not suitable for bush hammered work.
4 in.	Brick footing.
8 in.	Strips and footing.
14 in.	This bed can be split into 4 and 5 inch courses, but is ordinarily used solid for dimension stone.
16 in.	Generally splits into two 8 inch courses. Color is gray with a bluish tinge. Used for dimension stone.
12 in.	Can be split into two 6 inch courses. Is partly granulated. Used for footing.
15 in.	Fine textured stone, used for dressing.
12 in.	Texture is even, but the stone is slightly spotted with iron oxide. Used for dressing.
13 in. 12 in.	These courses are used for dressing, but on account of their hardness, they are difficult to cut. Occasional black spots consisting of pyrites, partially altered to iron oxide, occur in these beds.
9 in.	Somewhat granulated texture. Used for footing.
10 in.	Partially granulated course, used for footing.
18 in.	Granulated. Used for rough pier work and footing.
6 in.	Shelly course. Partly granulated.
12 in. 12 in. 13 in.	Fine, even textured stone, dark gray color, having a somewhat bluish tone. An occasional black or brown speck is observed in these courses.
5 in.	Rough footing stone.
14 in.	Dimension stone.
9 in.	Rough bed. Footing.
15 in. 16 in.	Coursing stone.
22 in.	Can be split into two or more courses. Used for pier work and footing.
15 in.	Works up into different thicknesses. Used for pier work, footing or dimension.
6 in.	Footing.
6 in.	Somewhat granulated course. Footing.
20 in.	Granulated. Splits into two 10 in. courses. Can be gotten out in dimensions as large as can be handled. Used for heavy footing.
20 in.	Can be broken up so as to make a 5 inch, and two 7 inch courses, or 5, 11, and 4 in. courses. This bed works well for rough hammered work but is somewhat flinty for bush hammerwork.

The above section of the Niagara limestone illustrates the general succession of strata in all three quarries. The thickness and texture of the stone in the different beds are not constant



NIAGARA LIMESTONE, WAUWATOSA.

1. A. F. and L. Manigold's Quarry.

2. Story Bros.' Quarry.

throughout the entire area, but, nevertheless, the succession in the different quarries is very similar. Portions of the quarries are illustrated in Plate XLII.

Laboratory Examination.

As has been said, the stone can be quarried in almost any desired dimensions, uniform in color and free from all impurities. As shown by samples in the Survey laboratory the stone from some of the courses dresses beautifully, although not as easily as an open, porous stone. The finished work has a very pleasing appearance, and is clean and clear enough for the finest constructional work.

Microscopical Examination.—Thin sections, examined under the microscope, show that the limestone is finely crystalline and very compact. (See Plate LXVII., Fig. 2.) The stone is composed mainly of irregular interlocking individuals of calcite and dolomite. An occasional irregular grain of quartz was the only other constituent observed. The limestone is free from all microscopically determinable constituents, that might be injurious.

Physical Tests.—Samples from Story Bros.' quarry were carefully tested in the Survey laboratory to determine the strength and durability of the Wauwatosa limestone. The results are given in the tables in Chapter VIII. The average specific gravity is about 2.823. The average porosity is 6.40%, and the ratio of absorption is 2.41%. The average crushing strength of the two inch cubes is 18,379 lbs. per sq. inch on bed, and 18,575 lbs. on edge. This is a low crushing strength for limestone of this character, but in justice to the stone, it must be said that this is not due to any inherent weakness, but to the fact that the samples were hammer dressed. Other samples which were sawed and used in the freezing and thawing tests, gave a crushing strength of over 25,000 lbs. per sq. in. The modulus of rupture was determined to be 2,129.5 lbs. per sq. in. These compressive and transverse strength tests are perfectly satisfactory, and furnish additional testimony to the

importance of this limestone as a constructional material. In most cases where comparisons are made with the tests on limestones from Illinois, Indiana, Missouri, and other states, the limestone from the Wauwatosa quarries shows evidently greater strength. (Compare Tables II. and XII., Chapter VIII.)

The results of subjecting samples of the Wauwatosa stone to alternate freezing and thawing are given in Tables VI. and VII., and show no loss in weight, and a higher compressive strength than was obtained from the experiments with fresh samples. The higher compressive strength was not the result of the test, but was due to the different ways in which the frozen and fresh samples were dressed. The fresh samples were hammer dressed, and the frozen ones were sawed. Samples that were gradually heated in a muffle furnace began to calcinate at a temperature of about 1200° F., and were practically destroyed at temperatures above this. (See Chapter VIII., Table X.) Samples treated with CO_2 in a moist atmosphere suffered no appreciable loss in weight. (See Chapter VIII., Table IX.) The faces of the samples treated with SO_2 in a moist atmosphere were slightly etched and faintly discolored, but there was no perceptible loss in weight. (See Table VIII.)

General Considerations.

The result of these various tests gives very satisfactory evidence of the suitability of the stone from this area, for all constructional purposes. The stone is strong, elastic, and gives evidence of durability, all of which naturally recommend it as a valuable building material. The stone takes a very pleasing rock face finish, and can be hammer dressed for almost any purpose. Many of the courses work under the hammer with some difficulty, but when once the stone is cut it will retain for many years the sharp outlines made by the chisel.

The volume of business done by the Wauwatosa quarries has decreased very materially during the last five years. A number of circumstances have contributed to this rapid decline in the

NIAGARA LIMESTONE, WAUWATOSA.

1. Front of First Baptist Church, Milwaukee, Wis.
2. Bridge Abutment, C., M. & St. P. Ry., near Milwaukee.
3. Dimension Blocks from Story Bros.' Quarry.
4. Loan and Trust Building, Milwaukee, Wis.

sale of the stone. Chief among these have been the fall in the price of brick, the general cessation in building, due to the panic of 1893, and the introduction into the market of inferior stone, which is quarried, cut, and dressed with much greater facility than the Wauwatosa stone. It is well known that the years of panic resulted in the curtailment of building operations with a lessened demand for building stone. The fall in the price of brick from $9.00 per M. in 1892 to $5.00 in 1896, and $3.50 in 1897, could not be met by the stone producers, and as a consequence the market for stone has been largely encroached upon by brick. The brick is so much cheaper that it is now being used for foundations, footings, and even bridges. The Indiana limestone, which is much softer and more easily cut and dressed than the Wauwatosa stone, has naturally encroached to some extent upon the Wauwatosa stone market.

All these are circumstances that cannot well be avoided with our present trade conditions. There are apparently only two ways to meet them, either reduce the price of the stone, or convince the people of its superiority over brick and imported stone. The former cannot be done unless the price of labor is lowered, and the latter will only come through the education of the people along this line.

The Wauwatosa stone is superior in strength and durability to any limestone imported from the adjacent states, and even though it is more costly, it ought to be used in many of the best buildings in the state.

Milwaukee has always been the largest consumer of the Wauwatosa stone, although many fine structures in other parts of the state have been built out of stone from these quarries. Some of the buildings in Milwaukee which are constructed out of Wauwatosa stone are shown in Plates XLIII. and XLIV. One of the finest bridge abutments on the C., M. & St. P. railroad, built out of this stone, is shown in Plate XLIII., Fig. 2.

The following are some of the more important buildings of Milwaukee in the construction of which Wauwatosa stone has been used.

Superstructure: Loan & Trust Building, Immanuel Church, St. James Church, Baptist Church, Y. M. C. A. Bldg., Phoenix Club, Residence of D. M. Benjamin, Plankinton Residence.

Foundation: Loan & Trust Bldg., C., M. & St. P. Depot, Pfister Hotel, Germania Bldg., Plankinton House (new part).

The Beloit College Chapel, Beloit, Wis., one of the prettiest college buildings in the state, was constructed out of this stone. See Plate XLIV., Fig. 2.

Immanuel Church, St. James Church, and the Y. M. C. A. building have all suffered from fire. Each one was repaired to show no trace of fire for less than $200.00 worth of stone. These actual tests of the extent to which this stone will withstand extreme heat are valuable in showing its suitability for heavy constructional work, in large cities, where conflagrations are among the possibilities.

Description of Individual Quarries.

STORY BROS.' QUARRY.

The quarry owned and operated by Story Bros. consists of one opening, 400 ft. wide, by 600 ft. long, with an average depth of 70 ft. The firm controls about 140 acres surrounding the opening. The stone is sold only in the rough. The quarry is in position to furnish stone for all basement work, including heavy and light footing, pier work, heavy bridge work, paving, and coursed and random ashlar. Any required dimensions up to 26 inches in thickness can be furnished.

Statistical Data.

Amount of capital invested: $25,000.00.

Facilities at hand for quarrying: 100 hp. Bullock Corliss Compressor, 100 hp. Sterling, 2 steam derricks, 10 tons each, 5 hand derricks, 1 10-ton hp. and 1 No. 10 Cameron pump. All machinery operated by compressed air.

Average number of employees: 50 in 1892; 25 in 1896.

Wages paid different classes of employees: Ordinary laborers, $1.25.

Cost of transportation: By teams only, 3 trips for team at $3.00 per day $.03 per cubic foot.

Average value delivered of each grade per cubic foot: Rubble, 1892,

NIAGARA LIMESTONE, WAUWATOSA.

1. Benjamin Residence, Milwaukee, Wis. 2. Beloit College Chapel, Beloit, Wis.
3. Plankinton Residence, Milwaukee, Wis.

8½c.; 1896, 6½c. Dimension, 1892, 30c; 1896, 23c. Footing, 1892, 2[illegible] 1896, 17c. Ashler, 1892, 25c; 1896, 20c. Paving 2½c to 2c.

Shipments for the past five years:

1892, building, $49,000.00; paving, $2,000.00.
1893, building, 45,500.00; paving, 2,500.00.
1894, building, 25,700.00; paving, 1,800.00.
1895, building, 21,400.00; paving, 1,100.00.
1896, building, 22,400.00; paving, 600.00.

THE MONARCH STONE CO. AND A. F. & L. MANIGOLD QUARRIES.

The Monarch Stone Co. and A. F. & L. Manigold have equipments similar to that of Story Bros., and they furnish stone for practically the same purposes.

WAUKESHA AREA.

The Waukesha limestone is very similar to that quarried at Wauwatosa. The quarries differ from those at Wauwatosa in the absence of the granulated beds. Two companies have been operating at this place,—Hadfield & Co. and the Waukesha Stone Co. (See Plate XLV.) The Hadfield quarry has been abandoned for several years, and the Waukesha Stone Co. is now the only firm operating at this place.

THE WAUKESHA STONE CO.

Quarry Observations.

The thickness of the beds varies from 3 to 22 inches. The joints strike about N. 40° E., N. 40° W., and N. 70° E., and occur at sufficient intervals to permit any reasonable dimensions being quarried. The color of the stone differs in the different beds. The color of certain beds is light buff, while others have a bluish tone. The stone is finely crystalline, and largely free from impurities. No drusy cavities or chert were observed. Occasional black or brownish flecks are the only noticeable imperfections.

5-18 ft.	Stripping
20-24 in. / 12 in.	Excellent stone for dressing. Somewhat broken up, but as good a stone as can be obtained in the quarry.
0 in.	Footing, somewhat rough.

11 in. 5 in. 8 in. 10 in. 16 in. 19 in.	Six beds of No. 1 stone, suitable for cutting and dressing; used for water tables, window caps, door sills, bases, etc. Also used for engine beds.
3 in.	Curbing.
15 in.	Footing stone; used for bridge abutments.
8 in. 20 in.	These courses are cut and dressed for monument bases, sills, etc. Quite readily cut and dressed when green, but hardens on exposure. A pale creamy color.
9 in. 9 in. 13 in. 12 in. 8 in.	These beds are used for building. Ordinarily called coursing stone.
8 in.	Footing. Broken into layers 2 to 3 inches thick.
12 in. 5 in. 7 in.	Footing.
24 in. { 3 in., 10 in., 11 in. 31 in. { 22 in., 9 in.	No. 1 fine, even grained, building stone; pale yellowish color. Small brown flecks are the only mar to uniformity in color.
12 in. 8 in. 11 in.	Footing. Used for heavy bridge work. Stone is somewhat rough.
3 in. 9 in. 8 in. 9 in.	Coursing stone. Uniform texture and fine grained.
7 in. 6 in. 7 in. 8 in. 5 in. 8 in.	Footing. These beds have a bluish gray color. They are not perfectly uniform in texture but have a blotchy appearance.
8 in.	Coursing stone with a fine grained uniform texture.

The above is a fair example of the different grades of stone that may be obtained from two of the quarries in this vicinity. A section of the Hadfield quarries from which dimension stone has been quarried would show a very similar section. Yet it must be remembered that other quarries opened a short distance from these contain stone which is only suitable for the manufacture of lime. The same beds which supply such excellent stone at these favorable localities are apparently so different, a short distance away, that no dimension stone of value can be obtained.

General Considerations.

The stone taken from these quarries, as well as that quarried at Wauwatosa, is equal in every respect to the Joliet or Lemont limestone of Illinois. The compressive strength of the Waukesha stone, as obtained by Fuldner and McDonald of the University of Wisconsin, is over 10,000 lbs. per sq. in. on 2 inch cubes.

The Waukesha limestone has been used very largely in the construction of buildings in Waukesha and elsewhere. A number of those buildings are shown in Plate XLVI. The Court House, shown in Plate XLV., Fig. 1, is an excellent illustration of what it is possible to accomplish with stone from these quarries. The building is perfectly fresh and clean, showing not the first evidence of discoloration. The stone has a rock face finish, and the walls are built in squared rubble masonry, the whole producing a most pleasing effect.

The market is not supplied with a more durable light colored limestone, or one that takes a more pleasing rock face finish. The fracture is clean and smooth, and for this reason the stone will remain longer free from accumulations of dust and dirt, than will a stone with a rough surface, similar to the Bedford limestone. The main drawback to the successful exploitation of the Waukesha stone is the difficulty with which it is cut and dressed. But, as has been said with reference to the Wauwatosa limestone, this is compensated for by its greater strength and durability.

GENESEE AREA.

Two quarries, one owned by the Genesee Quarry Co. and the other by Lee Bros., are located about a mile and a half north of the Genesee Post Office. These quarries do not differ materially from each other, except that certain beds are absent in one which are present in the other. The beds vary in thickness and texture in different parts of the same quarry. The stone in a certain bed, which is clear and uniform in one part of the quarry, may be imperfect in another part.

Description of Individual Quarries.

THE GENESEE QUARRY CO.

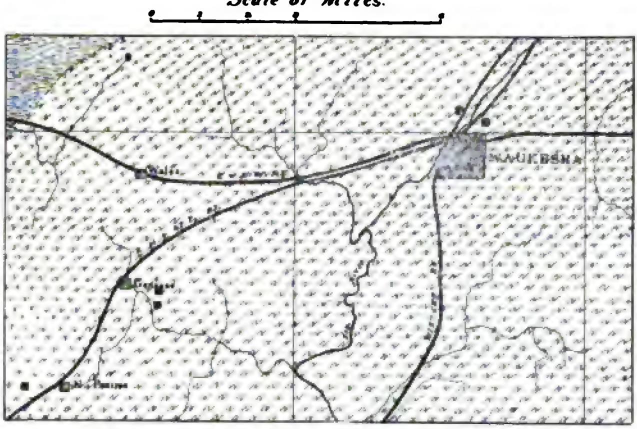
The quarry of the Genesee Quarry Co. is being operated on quite an extensive scale, and the company is shipping both rough and sawed stone. The quarry which is now being operated is situated on the side of a small knoll facing the south, and was opened many years ago.

Quarry Observations.

The opening is about 375 ft. long, 30 ft. wide, and 30 ft. deep. The stone occurs in beds, from 2 to 20 inches thick, which are broken into polygonal blocks by two sets of joints, striking N. 85° E. and N. 15° E. Practically no soil occurs on the surface. The stone is assorted into three grades, No. 1 cut, No. 2 cut, and coursing. The following section taken from the top to the bottom of the quarry indicates the thickness of the different beds and the purposes for which the stone in each is used.

10 ft.	Thinly bedded and much broken up, and may be classed either as stripping or rip-rap.
10 in. 17 in.	These two beds are No. 1 cut, and are considered the best in the the quarry for fine dressed work. The stone from these layers is clean and clear.
6 in.	Coursing stone.
10 in. 14 in.	Used for coursing. Not as good as the stone in the beds immediately below.
9 in. 8 in. 17 in. 11 in. 11 in.	The stone from these beds is No. 2 cut and coursing stone.
19 in. 3 in. 21 in.	Classed as No. 2 cut. The beds are not entirely uniform in texture, but contain occasional small drusy cavities.
17 in. 4 in. 14 in. 16 in.	This stone is No 2 cut. Used for coursing.
2 in.	Flagging.
7 in.	No 2 cut.
13 in. 8 in. 10 in.	Coursing. These beds are used for footing. Contain abundant nodules of chalk and chert.

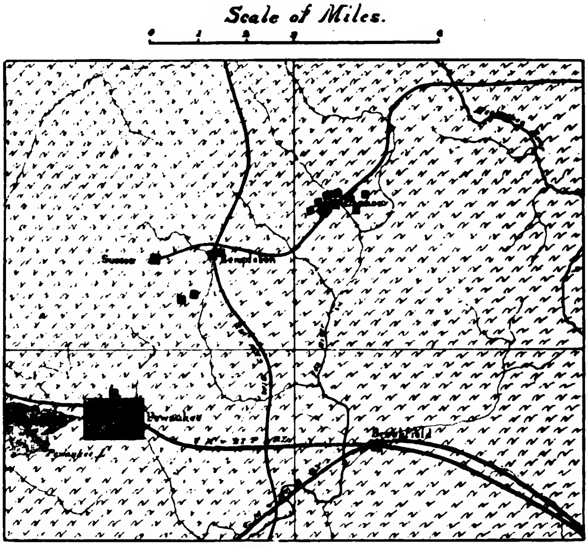
Scale of Miles.



Niagara Cincinnati ■ Quarry

WAUKESHA, GENESEE, AND PEWAUKEE AREAS.

Scale of Miles.



Niagara ■ Quarry

LANNON AND TEMPLETON AREAS.

General Considerations.

The beds in this quarry which are free from chert nodules and chalk have a very cheerful clear white or pale buff color. The stone works very readily, and is strong and durable. The product of the quarry, besides being sold in Wisconsin, is shipped into Illinois, where it easily competes with the Joliet stone. The great advantage which much of the stone from this quarry possesses is the ease with which it can be cut and carved. The stone from the Genesee Co.'s opening was not tested, on account of failure to send the necessary samples, but it is thought that if it had been tested the results would have corresponded very closely with those obtained for the stone from Lee Bros.' quarry.

LEE BROS.' QUARRY.

Lee Bros.' quarry is located on Secs. 23 and 26, in the town of Genesee, Waukesha county, about three quarters of a mile east of the Genesee Quarry Co.'s works. The quarry was opened in 1848 and operated until 1872. Since then it has only been worked at intervals, not being operated at present.

Quarry Observations.

Four openings have been made at as many different places on a small hill not far from the Genesee Quarry Co. Opening No. 1 has a face 40 feet long and 14 feet deep. Opening No. 2 has a face 50 ft. long and 10 ft. deep. Opening No. 3 has a face about 100 ft. long and 15 ft. deep.

The stone in these different openings occurs in beds from 2 to 20 inches in thickness. The major joints strike about N. 45° W., and the minor at about right angles. Other, less conspicuous joints, were observed striking N. 10° E., N. 35° E., and N. 75° W. The stone is broken into various sized blocks by these joints, and may be readily quarried with the aid of a crowbar and derrick.

Laboratory Examination.

Microscopical Examination.—Thin sections examined under the microscope show that the stone is finely crystalline, and com-

posed mainly of calcite and dolomite. Very little quartz was detected in the section, and no other impurities were discernible. The structure and composition of the rock are nicely illustrated in Plate LXVIII., Fig. 1.

Chemical Analysis.—The following chemical analysis of a sample of the stone from this quarry, made by Prof. W. W. Daniells, shows it to be a dolomite, with a small percentage of silica, and a much smaller percentage of aluminum and iron oxide.

$Si\ O_2$	6.32
$Al_2\ O_3$ / $Fe_2\ O_3$	1.02
$Ca\ CO_3$	50.96
$Mg\ Co_3$	41.75
	100.05

Physical Tests.—In order to determine the physical properties of the stone from this quarry, samples were tested in the laboratory, in the preparation of this report. The specific gravity was determined to be 2.831. The average porosity of the stone is 3.7%, while the ratio of absorption is 1.12%. (See Chapter VIII., Table V.) The loss in weight due to alternate freezing and thawing was not a measurable quantity. (See Chapter VIII., Table VII.) The loss in strength, as given in table VII., was 4,859 lbs. per sq. in. The sample which was submitted to extreme heat suffered only when the temperature was sufficiently high to produce calcination. Samples which were treated with carbon dioxide in a moist atmosphere showed no appreciable loss of weight, as shown in Chapter VIII., Table IX. Samples subjected to the action of SO_2 in a moist atmosphere suffered no loss in weight, although the surface of the samples became spotted with irregular patches of yellow. (See Table VIII.)

The crushing strength of the fresh sample, as given in Table II., is 36,731 lbs. per sq. in. on bed and 29,253 lbs. per sq. in. on edge. The modulus of rupture or transverse strength is given in Table III., and was determined to be 2,404.5 lbs. per sq. in.

WAUKESHA LIMESTONE.

1. Court House,
2. Carroll College, } Waukesha, Wis.
3. High School.

General Considerations.

A comparison of the crushing strength results with those obtained for specimens from other limestone quarries in this and neighboring states shows that from only two other quarries in this state were higher results obtained. The compressive strength of this stone is about 10,000 lbs. per sq. in. higher than the strongest limestone outside of Wisconsin. It is a remarkably strong stone, and is well adapted to all kinds of heavy constructional work.

The stone from this quarry has been used in a large number of buildings in different cities in the southern part of the state. The Commercial Block in Waukesha was constructed out of this stone in 1870. The Empire Mills in Milwaukee were built in 1864. The Hyde House in Janesville was constructed out of this stone in 1861. The Genesee Roller Mills were built out of this stone in 1854. These buildings, some of which were examined, testify to the durability of the stone when placed in the walls of a building. The different courses are clean and fresh, and show little or no evidence of discoloration or deterioration.

The quarry contains stone which is suitable for curbing, building, and other similar purposes. During the years 1895–96 about 100,000 ft. of curbing were quarried from these openings. During the last year no work has been done.

Statistical Data.

Amount of capital invested: $15,000.00.

Facilities at hand for quarrying: As stone occurs in layers, cross-bars and small derricks are all the implements employed.

Cost of transportation: By rail 1c rate.

Shipments for the past two years:

1895	100,000 ft. curbing.
1896	100,000 ft. curbing.

ZUNKER'S QUARRY.

At North Prairie, a few miles south of Genesee, there is located a small quarry owned by Wm. Zunker. The single opening is about 100 ft. long and 60 ft. wide. The quarry has not been operated for a number of years, but at one time it furnished stone for various constructional purposes.

LANNON AREA.

Lannon, a small town on the Menominee Falls railway, in the town of Menominee, Waukesha county, might be appropriately called the center of the curbing industry of Wisconsin. Nine companies are located within a few miles of Lannon, and are engaged mainly in the manufacture of curbing. (See Plate XLV. The heavier bedded stone is sold for building purposes, while some of the companies crush their rubble and rip-rap for macadam.

The companies which own and operate quarries at Lannon are Williams & Lannon, Blair & Larson, Davis Bros., J. H. Walsh, Frank Wallen, Harmon & Sons, Kiefer & Flannagan, Menominee Falls Quarry Co., and Sheridan Bros.

Each of these companies, with the exception of Sheridan Bros., was doing an extensive business during the summer of 1897. All the quarries possess essentially the same kind of stone, although subject to certain local variations. The stone compares very favorably with that which is obtained at Waukesha and Wauwatosa, being very similar in color and texture. The individual beds differ in texture and color, but taken collectively throughout the entire area, they compare very closely in the different quarries. The beds are not as massive as those occurring in the Waukesha and Wauwatosa quarries, and it is for this reason that the stone is so much more suitable for the manufacture of curbing.

Laboratory Examination.

Chemical Analysis.—The chemical analysis of the stone shows it to be a dolomite, or magnesian limestone. The following analysis of a sample taken about 15 ft. below the surface, from the Lannon Stone Co.'s quarry, was made for the company by Geo. M. Prentiss of Milwaukee:

Silica	3.96
Oxides of iron and aluminum	1.68
Carbonate of calcium	52.29
Carbonate of magnesium	42.27
	100.20

Iron and aluminum are present in such small amounts that they can scarcely be injurious to the rock.

Physical Tests.—Samples of the stone from the quarry of the Menominee Falls Quarry Co. were subjected to the complete series of physical tests, the results of which are embodied in the tables in Chapter VIII. The average specific gravity of the rock was determined to be 2.814. The average porosity was 3.17% and the average percentage of water absorbed amounted to 1.36%. These results indicate the close grained character of the rock.

The crushing strength is 31,936 lbs. per sq. in. on the bed, and 33,485 lbs. per sq. in. on edge. The transverse strength, expressed in the terms of the modulus of rupture, is 3,170.6 lbs. per sq. in. The crushing strength results are among the highest ever obtained for limestone, and show beyond a doubt that the stone is suitable for the heaviest kind of constructional work.

Samples which were subjected to alternate freezing and thawing lost nothing in weight after a period of 35 days' exposure. As indicated in Table VII., the crushing strength of the frozen sample was over 18,000 lbs. per sq. inch less than that of the fresh sample. This great difference in the crushing strength of the fresh and frozen samples is due in part at least to irregularities in the shape of the frozen cubes.

The results of the treatment with CO_2 and SO_2 are given in Tables VIII. and IX. Neither treatment had any appreciable effect on the weight of the samples.

Samples were subjected to extreme heat, but were not injured, until calcination began at a temperature of 1,000 to 1,200° F.

In general, these tests illustrate in a magnificent way the strong, stable character of the Lannon limestone. It is one of the best limestones on the market, and, with that from Waukesha and Wauwatosa, is not surpassed by any similar limestone imported from neighboring states.

Description of Individual Quarries.

WALLEN, WILLIAMS & LANNON, AND THE LANNON STONE CO.'S QUARRIES.

The quarries which are owned by Frank Wallen, Williams & Lannon, and the Lannon stone Co., are all situated about a mile west of Lannon, and immediately adjacent to each other. The beds which are worked do not change materially in the short distance separating the quarry openings, and there is, therefore, little if any difference in the color or texture of the rock in the three quarries. The following section of the Lannon Stone Co.'s quarry, given from the top to the bottom, represents well the succession of beds in the three quarries.

1½ to 3 ft.	Stripping.
6 ft.	Uncertain dimensions. Two of these courses, which are from 3 to 4 inches thick, are used for light brick footing. Also used for curbing.
6 in. 3 in. 4 in. 5 in. 7 in. 5 in. 5 in. 5 in. 5 in. 5 in.	These courses are all used for curbing. The 7 in. bed is an excellent stone for sills or light coursing. The stone has a light gray color.
4½ in.	Curbing.
21 in.	Shell. Sometimes used as footing.
8 in.	Very hard stone. Much broken up with seams.
5 in. 8 in.	Curbing.
5 in. 5 in.	Curbing.
10 in.	Coursing and curbing.
5 in. 5 in.	Curbing.
8 in.	A thin shell of 1⅛ in. in some places. Used for curbing and coursing.
10 in.	Coursing or two flags.
2½ in.	Flagging.
4 in. 5 in.	Curbing.
10 in.	Coursing or two layers of curbing.
12 in.	Coursing. Dark gray color.

The two most prominent sets of joints in these quarries, which strike N. 20° E. and N. 65° W., break the stone into dimensions suitable for almost any kind of constructional work. Peculiar curved jointing planes, looking much like the keel of a boat, were observed in these quarries.

WALSH'S QUARRY.

The quarry owned and operated by J. H. Walsh is located about half a mile west of Lannon. The opening has a depth of about 22 ft., in which the stone is exposed in layers of about the same thickness as those in the quarries previously described. The bottom layers, from 10 to 11 inches thick, have a uniform color and texture, and are considered the best in the quarry.

MENOMINEE FALLS QUARRY CO.

The following section, of one of the openings of the Menominee Falls Quarry Co., represents approximately the succession of beds as they occur north of the town.

8 in.	Top layer. Shelly. Unfit for use.
4½ in. 6 in. 4½ in. 4½ in. 6 in.	Five courses used for curbing.
3 in. 3 in.	Curbing.
12 in.	Shelly bed. Cavernous. Very elastic.
6 in. 6 in.	In places this bed is solid, but it generally splits into two curbing courses.
6 in. 8 in. 10 in.	Curbing courses. These courses, as well as those above, have a white or light buff color.
8 in. 8 in.	These beds are blue or bluish gray. Used for curbing.
16 in.	Solid bed. Coursing stone.
8 ft. 6 in.	The beds of this series are much broken up and vesicular. Used mainly for manufacturing macadam.
8 in. 10 in. 2½ in. 6 in. 10 in.	Coursing and curbing layers.

10 in. 5 in. 21 in. 10 in.	Fine, even textured stone, used for facing and curbing.
4 ft.	This is a shelly layer consisting of two courses of 12 inch footing, one course of 10 inch footing, and another of 14 inch footing.
14 in.	This bed is at the water level in the quarry.
23 in.	This is considered to be one of the best courses in the quarry. Even grained and light colored. The lower portion of the bed has a creamy color. An occasional chalk pocket occurs in this course. Large dimensions up to 30 ft. by 8 ft. may be easily quarried.
12 in. 16 in.	Color is light buff. Even texture. An ocasional drusy cavity filled with quartz.
18 in.	Occasional chalk pockets near the middle of the bed. Otherwise the rock is even textured.
30 in.	One streak of chalk pockets through middle of the layer.
16 in.	Numerous white chalk pockets.
12 in.	Texture is uneven. Occasional white chalk pockets.
16 in.	Clear, white stone, free from chalk pockets.

This is the only opening in which operations have been carried deep enough to strike the courses which contain chalk pockets. Very little of the rock is cavernous, only an occasional drusy cavity being observed in the lower courses.

DAVIS BROS., HARMON & SONS, AND KIEFER & FLANNAGAN QUARRIES.

The following section taken from Davis Bros.' quarry, which is located farther east than the last, is fully representative of the general succession of beds in all the quarries east of Lannon. The quarry owned by Sheridan Bros. was nearly filled with water when visited in the summer of 1897, and therefore nothing can be said concerning the stone in that quarry. Beginning at the top one finds the following beds.

5 ft.	Stone is used mainly for crushing. Some flagging.
7 ft. 7 in.	Twenty-five courses of curbing from 2 to 5 inches in thickness.
8 in.	Coursing and curbing.
9 in.	Two curbing courses, 4 inches thick.
8 in.	Coursing. Sometimes splits into two curbing courses.

NIAGARA LIMESTONE, LANNON.

1. Harmon & Son's Quarry.
2. Davis Bros.' Quarry.

3 in. } Curbing courses.
4 in. }

8 in. Coursing when solid. Splits and furnishes curbing.

2 in. Shelly. Flagging.

3 in. } In places solid. Curbing.
4 in. }

6½ to 7 in. }
6 " } Curbing.
6 " }

5½ in. Curbing.

6 in. } Often splits into three courses 4 inches thick. The color of the
6 in. } stone is blue, with a tinge of pink.

9 ft. 10 in. Beds are from 4 to 6 inches thick, with the exception of uppermost, which is 8 inches. Stone has a bluish color, often tinted with pink. Contains black flecks, similar to those observed in the Wauwatosa stone.

14 in. Often breaks into two courses 7 in. thick.

The jointing in these quarries permits of any reasonable dimensions being obtained. The joints strike about N. 65° W., and N. 30° E. in Davis Bros.' quarry. In Williams & Lannon's quarry they are the same, in the Hadfield quarry No. 1 they strike N. 80° W. and N. 64° E., and in Harmon & Son's quarry they strike N. 45° W.

General Considerations.

The major part of the stone from these openings is clear stock, free from deleterious constituents. The color of the beds near the surface is generally a white or delicate cream. Deeper within the quarry the beds generally have a bluish gray color. The stone is generally very compact and finely crystalline, being strong, and, to all appearances, durable. Some of the layers are difficult to work, while others can be cut and dressed with comparative ease. The most undesirable feature of the stone is the occurrence, in a few of the beds, of pockets of chalk. Pockets of this nature are undesirable on account of the ease with which they weather when exposed to the atmosphere, leaving a rough, unsightly surface.

The stone is preeminently a curbing stone, but when carefully selected it is very desirable for building purposes. It has been used very largely in Milwaukee and Chicago, where it competes

successfully with the stone from Joliet and Lemont, Ill. It has been found to withstand, without injury, the alternate freezing and thawing to which curbing is subjected many times during a year, at or near the surface of the ground. Besides curbing and building, the stone is crushed for macadam, sold for footing, or manufactured into paving blocks.

Probably certain of the companies operating quarries in this area will in the future be among the largest contributors to the limestone market of this and neighboring states. The stone is admirably suited to many uses, and if judiciously handled, it will certainly find a large and profitable market.

All of the companies are well equipped with machinery for quarrying and handling the stone. Steam drills, derricks, and bars constitute the larger part of the equipment. The following statistical data of the Menominee Falls, Wallen, and Lannon Stone Co. quarries will furnish an idea of the extent and equipment of the quarries of this area.

Statistical Data of the Menominee Falls Quarry Co.

Facilities at hand for quarrying:

3 50 H. P. engines. 5 steam derricks; 2 hand derricks; 2 stone crushers.

Average number of employees: 75.

Wages paid different classes of employees: $1.25 to $1.50.

Cost of transportation; $.02½ per cwt.

Average value of each grade per cu. ft.: $.02.

Shipments for three years:

1892—Pier 1,841 cu. ft; coping and curbing, 65,456 cu. ft.; paving blocks, 36,895; corners, sills, dimensions, etc., 360. Crushed 1,852 cu. yds; rubble, rip-rap, etc., 2,215 cords. Facing, footing, coursing, etc., 57,732 cu. ft.

1894—Coping and curbing 114,246. Paving blocks, 512,886.

1895—Coping and curbing 84,343 cu. ft; paving blocks, 205,350; crushed 23,648 cu. yds; rubble, rip-rap, broken stone, 4,915 cords.

Statistical Data of the Wallen Quarry.

Amount of capital invested: $3,000.00.

Facilities at hand for quarrying: 1 10-hp. and 1 20-hp. engine, 1 steam derrick, 2 hand derricks.

Average number of employees: About 18.

Wages paid different classes of employees:

Laborers	$1.50
Stone cutters	3.00

Cost of transportation: $.03 per 100 lbs.

Shipments for three years:

1894, curbing 25,000 ft.; paving, 75,000 blocks.
1895, curbing 30,000 ft.; paving, 100,000 blocks.
1896, curbing 27,500 ft.; paving, 150,000 blocks.

Statistical Data of the Lannon Stone Co.

Amount of capital invested: $10,000.00.

Facilities at hand for quarrying: 1 15-hp. engine; 2 steam derricks; 2 steam drills; 1 centrifugal pump; 1 steam jet pump; 4 push cars.

Average number of employees: 20.

Wages paid different classes of employees:

Laborers	$1.25 to $1.50
Stone cutters by piece work make, per day	$2.00 to $3.50

Cost of cutting and dressing stone per square foot:

4 in. curbing per linear ft	$ .03½

Cost of transportation: By rail, $.02½ for rough stone; $.03 for cut stone.

Shipments for 1896: 125 carloads.

TEMPLETON AREA.

A number of abandoned quarries are located in the vicinity of Templeton, several miles southwest from Lannon. (See Plate XLV.) The quarry of J. H. Kearney is about 2½ miles south of Templeton. Another quarry, known as the Forrestall quarry, is located near the one owned by Kearney, while a third quarry at Templeton, owned by Hummel & Elliott, has furnished a small amount of dimension stone. Another quarry in this vicinity was opened about six years ago, for the manufacture of quicklime, by Bentley, Lund & Co., then known as the Wisconsin Lime and Stone Co.

Quarry Observations.

At present all of these quarries have been abandoned. The stone in each of the openings differs somewhat in color and texture, although having a general similarity. The joints and bedding planes are well defined in all the openings. The joints strike N. 80° E. and N. 55° W. in the Kearney and Forrestall quarries, and N. 60° W. and N. 50° E. in the quarry of Hummel & Elliott. In the Kearney quarry the peculiar curved joints noted in the Lannon quarries were again observed. One of these joints gradually changed direction from N. 55° W. to N. 37° W., through an arc of 18°. The beds range from 2 to 14 inches in thickness, and stone of any reasonable lateral dimensions can be obtained.

All of the quarries in this vicinity are located on comparatively level land, and the stripping is generally light, not exceeding 6 or 8 feet. The upper beds are, as a rule, thinner than those deeper within the quarry. Some idea of the stone occurring in these quarries may be obtained from the following partial section taken from Kearney's quarry:

4 in.	Comparatively uniform in color and texture. The upper surface has been smoothed and striated by the action of the glaciers.
6 in. 2 in.	These are flagging and curbing courses. Quite uniform in texture.
6 in. 4 in. 5 in.	These beds, comprising 22 inches, are considerably broken up, and will not furnish as large dimension stone as the courses below. Curbing and flagging.
13 in.	Coursing stone. In places this bed splits into two curbing courses.
6 in. 7 in. 6 in. 9 in. 14 in. 10 in.	These courses may be used for various purposes. either coursing or curbing, depending upon the thickness. A few black specks are scattered unevenly through the matrix of the rock, but are only noticeable upon close inspection.

The beds below this level were concealed by water, which filled a large part of the quarry.

General Considerations.

The stone generally has a uniform texture, but occasionally carries small drusy cavities lined with calcite. Certain beds

appear to be especially well suited to sill and cap work, but, as a whole, the stone appears to be best suited for building, curbing, and cross walks. Paving blocks and macadam have been manufactured quite extensively from this stone, but for these purposes the stone appears to be rather soft. Quicklime has been manufactured at several of the quarries, and a number of years ago it was shipped quite extensively to Chicago and Milwaukee.

From 1846–49 a number of buildings were constructed in this vicinity out of stone from these quarries, among which may be mentioned a school house, church and dwelling house. A close examination of these buildings shows that the stone used in the walls is almost in perfect condition. The stone has neither discolored nor weathered perceptibly and the chisel and hammer marks are as clean cut today as they were when the buildings were first erected.

PEWAUKEE AREA.

Two quarries are located at Pewaukee, which have been operated more or less for a great many years. One of these quarries is owned by C. A. Cairncross, and the other by Caldwell & Nelson. CAIRNCROSS'S QUARRY is now exploited mainly for the manufacture of quicklime, though certain courses are used for building and other constructional purposes. The limestone is fossiliferous and contains small drusy cavities lined with calcite.

The quarry owned by CALDWELL & NELSON is about a mile east of the city of Pewaukee. The stone is used mainly for building and curbing purposes. The upper courses for a depth of 4 or 5 ft. are unsuited for anything but the manufacture of quicklime, but the beds below this horizon, are 3 to 8 inches in thickness, and suitable for light constructional purposes. As observed in the quarry, the stone is hard, finely crystalline, and of a grayish color. When thoroughly seasoned it is almost white.

There is apparently a sufficient supply of good limestone in this vicinity to meet all the demands of the local market. It is

possible that a sufficient amount of good stone might be obtained to warrant quarrying on a more extensive scale.

BURLINGTON AREA.

Near the city of Burlington, in the southeastern part of the state, is located a small quarry owned by W. A. Aldrich. At one time this quarry was worked quite extensively to supply the local market, but of late years it has been abandoned. At the time the quarry was visited in 1897, the opening was largely filled with water, which prevented an inspection of the stone as it occurs in the beds.

Laboratory Examination.

Samples were sent to the Survey, and a complete series of physical tests were made to determine the quality of the stone. The results of these tests are recorded in the tables in Chapter VIII. It was found that the specific gravity of the stone averaged about 2.78, the average porosity is 8.32%, and the average ratio of absorption is 3.26%. (See Chapter VIII., Table V.) The crushing strength of the stone is given in Table II., and shows an average of 12,827 lbs. per sq. inch. Samples were subjected to alternate freezing and thawing, from which they suffered no loss of weight after a period of 35 days. The loss in crushing strength due to freezing and thawing, as given in Chapter VIII., Table VII., amounts to 5,273 lbs. per sq. in. Samples which were tested to determine the effect of extreme heat were not destroyed, until a temperature of 1,000° F. was reached. The samples which were treated with carbon dioxide suffered no loss in weight. The samples treated with sulphur dioxide were slightly discolored, and lost .40 of a gram on a mass of a little over 35 grams weight.

General Considerations.

The stone from this quarry is somewhat laminated, and has a mixed color. Certain courses are reddish brown, while others are yellow. The texture is fairly uniform, but differs in the different beds.

The laboratory examination of the stone shows it to be sufficiently strong and durable for ordinary foundation and light bridge construction. It would be difficult to point out without an examination of the stone in the quarry any other purposes for which the stone may be suitable. The stone has been used in the construction of arches and bridge abutments spanning the White river, in the vicinity of Burlington, and has been used in the construction of foundations to many of the business blocks.

In this vicinity the cobble stones (limestone), which are found abundantly in the drift, have been used quite extensively in the construction of the walls to the dwelling houses in the country.

RACINE AREA.

The quarries in the Niagara limestone in the vicinity of Racine are exploited mainly for the manufacture of quicklime and crushed rock for macadam. Three important quarries, engaged mainly in the manufacture of these products, are operated near this place, the HORLICK LIME AND STONE CO., the FOX LIME & STONE CO., and JOHN O'LAUGHLIN.—One of the quarries of the Horlick Lime & Stone Co. and the quarry of John O'Laughlin are located at a station north of Racine, known as Ives.

The stone which is quarried from all the different openings has essentially the same characteristics. It is a rough vesicular limestone, carrying occasional crystals of pyrite or marcasite, which often discolor the stone by weathering. The stone is distinctly bedded, but the different courses vary largely in thickness. The lower courses are as much as 30 inches in thickness, while the upper ones often do not exceed 8 or 10 inches. The different beds are broken into various sized polygonal blocks, by jointing planes, which strike N. 60° W., N. 45° E., and occasionally N. 20° E. In most of the quarries the stone is badly broken up, making it rather difficult to obtain large dimensions. The general color of the stone is bluish gray. The texture is uneven, and the different beds contain numerous small irregular

cavities, on account of which the stone is known as hackly limestone.

As mentioned above, the stone from these quarries is used mainly for the manufacture of quicklime and macadam. The Horlick Lime & Stone Co. and the Fox Lime & Stone Co. furnish dimension stone for rough foundation work, but none of it is cut or dressed for building purposes. The stone from the John O'Laughlin quarry is used exclusively for macadam. Some paving stone was manufactured a few years ago at the Fox Lime & Stone Co.'s quarry, but it did not prove satisfactory, and the work was abandoned.

CEDARBURG AREA.

A single quarry, owned by John Groth, is located at Cedarburg. Two openings have been made, from which the stone is quarried almost exclusively for the manufacture of lime. For the most part, the stone is light, porous and fossiliferous, similar to that which is quarried at Germantown for the manufacture of quicklime. This rock is very finely porous, and in the sunlight the many small crystals, lining the walls of the minute pores, throw out a myriad of sparkling reflections. The stone works readily under the hammer, and has a pleasant creamy color. The stone in other beds of the quarry differs from this in being compact, brittle, and finely crystalline. The stone from these beds is only suitable for the manufacture of quicklime. The light, spongy type, when it occurs in sufficiently large dimensions, can be used to advantage for building purposes.

GRAFTON AREA.

Two companies operate quarries in the vicinity of Grafton, both of which are engaged mainly in the manufacture of quicklime. These companies are the Anschuetz Co., located about a mile and a half south of Grafton, and the Milwaukee Falls Lime Co., about a mile south of Grafton.

THE ANSHUETZ CO.

The stone quarried from the Anshuetz Co.'s opening is very similar to that quarried from the Groth quarry at Cedarburg. Both the flinty and spongy kind occur. The rough and flinty beds are at the top of the quarry and are all used in the manufacture of quicklime. The lower 15 ft. are composed of the softer stone, which is used mainly for building purposes. The color is almost white and the stone is apparently free from impurities. Occasionally portions of the beds are colored yellow, and when the stone is used in the superstructure of a building, these should be avoided. The stripping is light, being from 2 to 3 feet thick. The joints strike about N. 40° E. and N. 52° W., and the stone can be gotten out in dimensions sufficiently large for ordinary coursing stone. It will serve remarkably well for the construction of ordinary buildings. Blocks 4 ft. by 4 ft. by 10 ft. can be quite easily obtained.

THE MILWAUKEE FALLS LIME CO.

The quarry owned by the Milwaukee Falls Lime Co. was opened in 1892, and the stone is used almost exclusively for the manufacture of lime. The opening is 800 ft. long, 400 ft. wide, and 40 ft. deep, showing that a large amount of stone has been quarried at this place.

This quarry serves as an excellent illustration of how economically a quarry may be worked. The company has utilized all the natural advantages of the place, and the quarry has been well equipped with all necessary machinery. Cedar Creek has been dammed for the purpose of obtaining power, which is transmitted by an air compressing engine to operate the drills and lift the cars up the incline to the kilns. Mr. G. A. Mace, who is manager of the company, has so conveniently and systematically arranged the work that the lime is manufactured at what might be regarded as a minimum cost. Many of the companies in the state, that are engaged in quarrying building stone, might in a similar manner minimize the cost of production.

PORT WASHINGTON AREA.

About six miles north of Port Washington is located a quarry, owned and operated by the Dricker Co., which is engaged mainly in the manufacture of quicklime. The quarry is not being worked very extensively at present, but has produced a considerable amount of quicklime in past years. Rough stone for foundation and other purposes can be obtained at this quarry.

GRIMMS & BRILLION AREA.

The Cook & Brown Lime Co. operate an extensive quarry at Grimms. The company is engaged almost exclusively in the manufacture of quicklime, although the stone from certain beds in the quarry might be used to advantage for rough constructional work.

The Ormsby Lime Co., located at Brillion, was opened in 1883, and is engaged exclusively in the manufacture of quicklime. If properly quarried, some of the stone from this quarry might also be used for constructional purposes.

MAYVILLE AREA.

The quarries at Mayville are two in number, and are owned by O. S. Cochran and Henry Rudebusch. The Cochran quarry, located about 2½ miles north of Mayville, has been abandoned for several years. The stone from Rudebusch's quarry, located 4 miles south of Mayville, is used principally in the manufacture of quicklime. The quarry is very large, and from the lower beds an even textured, hard stone, from 7 to 14 inches in thickness, is quarried. The stone is badly broken by joints, and it is difficult to obtain stone of large lateral dimensions. As a constructional stone it is only used for local purposes.

KNOWLES' AREA.

Two quarries are operated in the vicinity of Knowles, one by Frank S. Bauer and the other by Happe Bros. There is little difference in the stone from these quarries although they are located some distance apart.

HAPPE BROS.' QUARRY.

The quarry owned and operated by Happe Bros. is located on the side of a small hill about two miles north of Knowles. The face of the quarry is about 28 feet deep. The stripping is very light, not being over 2 ft. The upper 10½ ft. of stone are much broken up, and are used mainly for the manufacture of quicklime and crushed stone. The remaining 17 ft. consist of beds ranging from 3 to 12 inches in thickness.

The upper of these beds are softer and more easily worked than those deeper in the quarry. The stone is somewhat laminated, and, with the exception of the lowest bed, which contains large cavities often lined with calcite crystals, it is essentially solid. The main vertical joints strike N. 55° W. and N. 45° E.

From the larger beds good coursing stone can be obtained, and in past years a considerable amount was quarried for this purpose.

BAUER'S QUARRY.

The quarry which is owned by F. S. Bauer is located on a small hill a short distance south of Knowles. It has a face of about 17½ feet. The floor of the quarry is somewhat uneven, being arched in several places. The beds range in thickness from 3 to 12 inches. Most of the stone has a very pleasing light buff color, is fine grained, and has a uniform texture. Some of the lower courses have a hackly texture, which unfits them for fine work, but the main difficulty is experienced in obtaining large dimensions. Much of the stone can be easily cut and dressed, and has altogether a very pleasing effect.

Laboratory Examination.

The stone from this quarry was carefully examined in the laboratory of the Survey, microscopically, chemically, and physically.

Microscopical Examination.—The microscopical examination shows a compact crystalline rock, composed essentially of calcium magnesium carbonate, with scarcely any quartz or other

impurities. The individuals are of uniform size and interlock in such a manner as to suggest a very strong stone.

Chemical Analysis.—The following analysis, made by Prof. W. W. Daniells, shows that the stone from this quarry is almost a pure dolomite, essentially free from impurities, such as quartz, iron, and aluminum, which usually occur in larger amounts in ordinary limestone and dolomite.

$Si\ O_2$	.022
$Al_2\ O_3$ $Fe_2\ O_3$	.005
$Ca\ CO_3$	54.740
$Mg\ CO_3$	45.07
Total	99.837

The stone is over 99% pure dolomite ($Ca\ MgCO_3$).

Physical Tests.—The specific gravity of the rock was found to be 2.70, the percentage of water absorbed averaged 1.66%, and the average porosity was 4.43%. (See Chapter VIII., Table V.) The crushing strength of the rock, as indicated in Table II., is 29,189 lbs. per sq. inch on bed, and 32,171 lbs. per sq. inch on edge. The transverse strength, given in terms of the modulus of rupture, was determined to be 1,609 lbs. per sq. inch. Samples were subjected to alternate freezing and thawing, but after 35 days' exposure, there was no appreciable loss in weight. (See Chapter VIII., Table VI.) The loss in compressive strength due to freezing and thawing, as shown in table VII., amounted to over 13,000 lbs. per sq. inch. This difference between the crushing strength of the fresh and frozen samples may be partly accounted for, as in certain of the previous experiments, by the imperfect shape of the frozen samples.

Samples of the limestone were subjected to the action of carbon dioxide, but showed no appreciable loss in weight. Other samples, subjected to the action of sulphur dioxide, were colored yellow, and lost .07 of a gram in weight on a mass of about 181.5 grams, which is an almost inappreciable amount. Small transparent crystals of magnesium sulphate formed over the entire surface of the samples.

The sample which was subjected to extreme heat was little affected at a temperature of 1,000° to 1,200° F., being slightly calcinated at the corners. (See Chapter VIII., Table X.)

These experiments show that the rock from this quarry is well suited for either heavy or light constructional work. It is strong and durable and its freedom from impurities insures permanence of color.

MARBLEHEAD AREA.

A large amount of stone is quarried in the vicinity of Marblehead, but it is used mainly in the manufacture of quicklime. Three companies have opened and are now operating quarries in this vicinity, the Marblehead Lime & Stone Co., Nast Bros., and Geiger. (See Plate XLVIII.)

Quarry Observations.

All the stone from these quarries possesses the same general characteristics. The beds are in some places horizontal, and in others they are arched up into low anticlines. The rock is badly broken up by joints, many of which can only be detected in the process of dressing.

The beds which have been worked for dimension stone often possess fine planes of lamination, along some of which the stone splits with comparative ease. A 10 inch bed cannot always be depended upon for 10 inch coursing stone. Five inch courses, for the same reason, cannot always be depended upon for curbing. Other beds are vesicular, and for this reason are unfit for dimension blocks.

In Geiger's quarry the joints strike N. 45° E. and N. 45° W., and occur at irregular intervals, making the possibilities for large dimension blocks very uncertain. Clay seams, which extend to a depth of about 4 feet, also occur in this quarry.

The large size of the different openings shows that operations have been quite extensive during the past years. The character of the stone and the manner of occurrence is best illustrated by the following vertical section taken from the Marblehead Lime & Stone Co.'s quarry:

25 ft. The beds of these upper courses are of uncertain dimensions. The lowest beds occasionally attain a thickness of 22 inches, but these may be quite readily split into beds of much smaller size. The surfaces of many of the beds of this horizon are rough and often undulatory. Very little of the stone from these beds is available for dimensional purposes.

3 ft. 8 in. This is the combined thickness of a number of beds between two irregular floors. The stone in these beds is solid, finely crystalline, and compact.

17 in. Splits into four layers, which are compact and finely crystalline.

20 in. Consists of two compact and two shelly beds. All are somewhat vesicular.

11 in. Compact bed.

6 in. Shelly.

8 in. Compact, except for the presence of a few small cavities.

9 in. Splits into four shelly layers.

8½ in. } 10½ in. } Two compact and finely crystalline beds. Most suitable beds for coursing observed in the quarry.

3½ in. } 4 in. } Finely crystalline. Curbing.

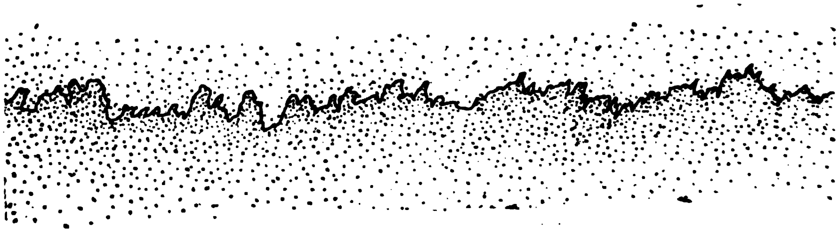
3 ft. Occurs in beds from 2 to 6 inches thick. The beds are laminated and the rock is finely crystalline. The color is bluish gray.

4 in. } 8 in. } A few cavities in the rock from these courses.

22 in. Consists of five beds ranging from 2 to 6 inches in thickness.

18 in. Very vesicular. Three beds, 5, 6, and 7 inches thick.

12 in. Consists of three finely laminated beds.



IRREGULAR BEDDING PLANE IN MARBLEHEAD LIMESTONE.

FIG. 4.

The limestone has a general grayish white color, with occasionally the faintest tint of buff. Pyrite occasionally occurs along the jointing or bedding planes. Some of the bedding

planes are irregularly toothed, as represented in Figure 4. Fortunately, this irregular bedding is not so injurious to the stone as it is in the Indiana Bedford quarries, where it occurs on a much more extensive scale.

Laboratory Examination.

In order to ascertain the relative value of the stone for constructional purposes, samples from the Marblehead quarry were analyzed and tested in the Survey laboratory.

Microscopical Examination.—The examination of the thin section under the microscope shows the rock to be compact, thoroughly crystalline, and uniformly fine grained. It consists essentially of calcite and dolomite, with an occasional very small grain of quartz and flecks of iron oxide. The stone is remarkably free from quartz or other impurities.

Chemical Analysis.—The following chemical analysis of a sample from the Marblehead Lime and Stone Co.'s quarry was made by Prof. W. W. Daniells.

SiO_2	2.12
Al_2O_3 / Fe_2O_3	.59
$CaCO_3$	53.51
$MgCO_3$	43.54
Total	99.76

It will be observed that the stone is nearly a pure dolomite. The content of silica, iron, and aluminum are both very small.

Physical Tests.—The results of the physical tests are given in the tables in Chapter VIII. The average specific gravity of this limestone is the highest of any stone tested from this state, being 2.852. The average porosity is .77%, while the ratio of absorption is only .28%, which is one of the lowest results obtained for limestone in this state.

The maximum crushing strength is phenomenal for limestone, being 42,787 lbs. per sq. inch on bed, which is nearly 18,000 lbs. higher than the strength obtained for any limestone, dolomite, or marble occurring outside of Wisconsin. The strength of this limestone even surpasses that of the Fourche

Mountain granite of Arkansas by 8,637 lbs., while it comes within 1,186 lbs. of equalling the strength of the Montello, Wis., granite, which is thought to be the strongest true granite yet tested in the world. The average crushing strength of the limestone is 41,615 lbs. per sq. inch. The transverse strength, in terms of the modulus of rupture, is 3,632.8 lbs. per sq. in., which shows it to be one of the best suited rocks for uses where high transverse strength is required.

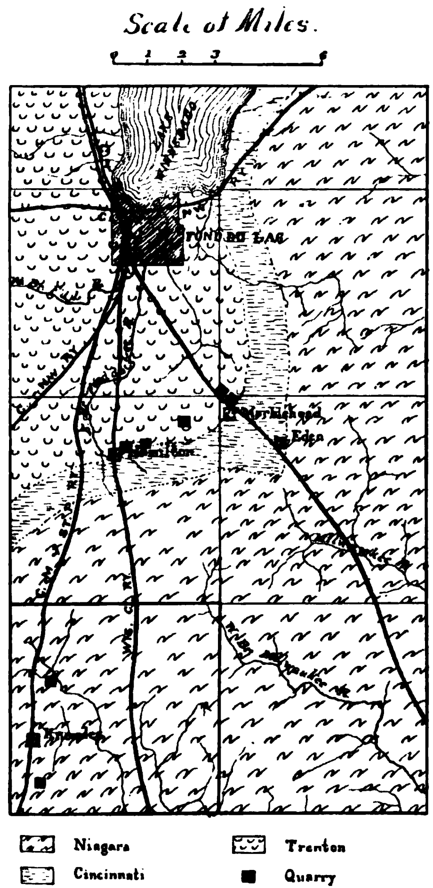
Samples were subjected to alternate freezing and thawing, but suffered no loss of weight after a treatment of 35 days. (See Chapter VIII., Table VI.) The loss in compressive strength, as given in Table VII., is 14,254 lbs. per sq. inch. This very considerable difference is partly accounted for by the fact that the frozen samples were not as carefully dressed as the fresh ones.

The samples which were subjected to extreme heat were transformed into quicklime along the edges at a temperature of about 1,000° to 1,200° F. At a temperature of 800° the stratification planes were intensified, but this was the only noticeable change until the point of calcination was reached.

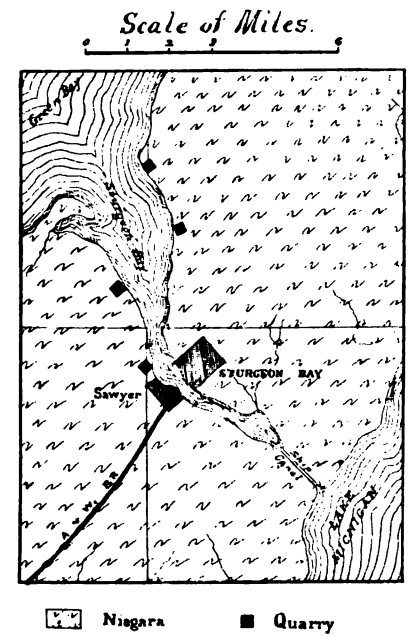
The samples that were treated with CO_2 were apparently uninjured thereby. The treatment with SO_2 colored the sample with patches of yellow and caused a precipitation of $MgSO_4$ on the surface, all of which was attended with no appreciable loss of weight.

General Considerations.

The result of these tests places the Marblehead limestone ahead of all others in strength, and equal in durability to that from other quarries in the state. The stone is necessarily somewhat difficult to dress, but from certain courses it may be obtained in dimensions suitable for sills, flagging, curbing, and building. The stone produces excellent lime and the crushed rock is among the best that can be obtained from the Niagara limestone formation.



HAMILTON, MARBLEHEAD, AND KNOWLES AREAS.



STURGEON BAY AREA.

HAMILTON AREA.

The stone exploited from the quarries at Hamilton is very similar to that which is quarried at Marblehead. The quarries at this place are three in number, and are owned and operated by the Hamilton Lime & Stone Co., Seth Sylvester, and Thos. Costello. The largest quarry is that of the Hamilton Lime and Stone Co., the stone being used very largely for the manufacture of quicklime. The Costello quarry is located about half a mile east of the Hamilton quarry, and has not been operated for four or five years. The Sylvester quarry is about a quarter of a mile east of the Hamilton quarry and is worked mainly for dimensional stone.

Quarry Observations.

In outward aspect the stone is very similar to that which is quarried at Marblehead. It occurs in well defined beds, which are cut by joints striking N. 45° W. and N. 50° E. The beds are also broken by incipient joints known by the quarrymen as "blind" seams. These joints are so close that their presence can, as a rule, be detected only when the stone is broken with the hammer. The beds are frequently arched in domes and basins, often having a very considerable elevation or depression.

General Considerations.

The rock is finely crystalline, and generally difficult to work. For this reason, it has been exploited mainly, either for the manufacture of lime or crushing for macadam. That which is sold for constructional purposes is rough "corded" stone. The stone does not dress readily with a hammer, and for this reason the development of the quarries for building stone has not been very large. The Sylvester quarry is the only one which is now exploited exclusively for this purpose, and the semi-active condition of this quarry indicates that difficulties are encountered which make successful quarrying uncertain.

SHEBOYGAN AREA.

In the vicinity of Sheboygan very little stone is quarried for constructional purposes. The main quarry is that of the Sheboygan Lime Works, from which the stone is mainly used for the manufacture of quicklime. Some dimension stone has been furnished for local consumption, mainly for foundation purposes. The stone is a hard bluish gray limestone, usually rough and vesicular. It is distinctly bedded, and occurs in courses from 3 to 12 inches in thickness. The stone is apparently very much broken by joints, although some of the fractures may have been produced by blasting. The peculiar stylolite bedding planes, shown in Figure 4, were observed here as in the Marblehead quarries.

The stone from the lowest three feet in the quarry, if rightly worked, could be used to advantage for ordinary constructional purposes, but the heavier beds of the upper part of the quarry, on account of their irregular, hackly texture, are unsuitable for such work.

SHEBOYGAN FALLS AREA.

The rock quarried at Sheboygan Falls does not differ greatly from that which is quarried at Sheboygan. The color is a bluish gray, and the stone occurs in beds ranging from 6 to 20 inches in thickness. The lowest beds, 6 inches thick, are considered the best for building. The frequency of jointing planes does not permit the quarrying of large dimensions.

The stone is used mainly for the manufacture of quicklime, but is also used for local building purposes, mainly in foundations. The quarry is owned and operated by Henry Kohlhagen. It is scantily equipped with machinery, the stone being quarried mainly by blasting.

PEEBLES AREA.

A small quarry is operated by the C. & N. W. Ry. Co. at Peebles, a small station about 5 miles northeast of Fond du Lac. The quarry is situated at the top of a bluff, immediately adja-

cent to the railroad, and has a working face of about 24 ft. The stone is quarried from the limestone beds immediately above the Cincinnati shales. The following is a section of the quarry:

4 ft.	Stripping.
6 ft.	Rip-rap. Suitable only for crushing.
6 in. 6 in.	These courses sometimes run solid. Used only for rubble.
1 ft. 9 in.	This course generally breaks into three or four beds. It is partly rip-rap and partly rubble.
2 ft. 6 in.	This course breaks into three 6 in. beds and one 12 inch bed. The latter is used for bridge stone, but is rough and vesicular.
3 ft. 6 in.	This bed breaks into four courses, which are used for bridge abutments. It is known as rubble stone.
3 ft. 6 in.	Rip-rap.
2 ft.	Clay shale. Lower limit was not exposed and it may extend to a depth of many feet.

The stone is much broken by joints, on account of which no large dimensions can be obtained. The upper beds contain many small cavities, most of which are filled with chalk and chert. Small crystals of pyrite and calcite are also found in the different beds. The dimensions which can be obtained are very uncertain.

The stone from this quarry is not well suited for either building or bridge construction. The rough and irregular texture interferes with cutting and dressing, while the joints are too close to permit the quarrying of large dimensions.

KEWAUNEE AREA.

A single quarry is located at Kewaunee, from which the demands of the local stone market are supplied. The quarry is owned by Mr. Moore and was operated in 1897 by John Bergman. The opening is shallow, but the lateral dimensions are quite large. From twelve to thirteen thousand cords of stone have been sold since the quarry was opened. The quarry is located about 2½ miles west of the city, and the stone is shipped by barge down the Kewaunee river to the lake.

The beds are much broken up, giving no indication of very

large dimensions. The stone is used mainly for crib work, and for this purpose it answers very well.

STURGEON BAY AREA.

An abundance of Niagara limestone occurs within a few miles of Sturgeon Bay. The large demand for stone in the construction of the government breakwaters, piers, and cribs has assisted in developing several large quarries in this vicinity. Four quarries are now being operated, two on the northeast side of the bay, and two on the southwest side. (See Sketch Map, Plate XLVIII.) These quarries are operated by the Laurie Stone Co., Latham Smith, Frank Hagen, and Termensen & Jensen. The last named quarry is known as the Washington Stone Co.'s quarry.

Quarry Observations.

The stone which is quarried from the different openings does not differ very greatly, either in color or texture, and has a general resemblance to the limestone quarried at Hamilton and Marblehead. It is similarly laminated and has a color ranging from buff to bluish gray. The stone is hard and brittle, and in some places has a hackly texture. It is generally too hard to dress easily, and certain of the beds contain occasional drusy cavities. Several of the darker courses appear to be bituminous. Large dimensions can be quarried from some of the beds, while others are so badly fractured that it is scarcely possible to obtain blocks of any reasonable size.

The joints at the Laurie Stone Co.'s quarry strike about N. 25° W. and N. 55° E. At Hagen's quarry they strike N. 33° W. and N. 60° E., while at the Washington Stone Co.'s quarry they strike N. 25° to 30° W. and N. 50° E. The following sections, the first taken from the Laurie Stone Co.'s quarry, and the second from the Washington Stone Co.'s quarry give the general characteristics of the stone from all the quarries of this area.

Laurie Stone Co.'s Quarry.

2 to 3 ft. Stripping.

8 ft. The beds in this portion of the quarry are from 4 to 6 inches thick, and are used mainly for pier work.

12 in. } These beds are evenly laminated and are classed as rubble.
9½ in. }

14 in. } These two beds are probably freer from drusy cavities than any
10 in. } other layers in the quarry.

7½ in. Somewhat vesicular. Between this bed and the adjacent ones, occur thin layers of blue clay. A thin layer of clay is found between many of the beds.

9 in. This course is even textured and clear.

4 in. Laminated layer.

8½ in. Contains a great many drusy cavities.

10½ in. This course breaks into three beds about 6 in. in thickness. Laminated and contains occasional drusy cavities.

13½ in. This course is laminated, and splits into two beds of 6 and 7½ in. respectively. The color is light, almost white.

8 in. }
8 in. } These beds contain an occasional drusy cavity.
3½ in. }

8 in. } The stone in these courses has a bluish tinge. It is laminated,
6 " } hard, and brittle.

The Washington Stone Co.'s Quarry.

½ to 2 ft. Stripping.

7½ ft. Soft white to buff limestone, containing irregular drusy cavities. The rock in these courses is very much broken up.

1 ft. Laminated stone.

4 ft. 8 in. Soft, hackly beds.

4 ft. Light colored stone. Somewhat laminated.

8 ft. Very hard hackly beds from 6 to 8 inches thick. Much broken up. Very dark slate color.

14 in. This course is laminated, but not quite as distinctly as certain other courses. This course and the ones immediately beneath it could be cut with little difficulty, into sills, caps, and steps.

19 in. This course contains a number of small cavities, and is quite rough.

4 in. Shelly layer.

12 in. This layer has more of a gray than a blue color.

13 in. This course is somewhat more laminated than the others, and can be split into two or more courses. The liminæ are indicated by dark lines.

5¼ in.	This course is soft and contains many irregular cavities.
5¼ in. ¾ in.	Shows wavy lamination.
7¼ in. 5 in. 5¼ in.	Shows wavy lamination. Hard and refractory.
12 in.	Solid bed, with an occasional sedimentary plane.
4 in.	Consists of two or three small laminæ.
9 in.	Hard, laminated stone in which an occasional cavity occurs.
6¼ in.	Hackly limestone. Softer than the preceding beds, and contains many small pores.
13 in.	Solid bed, somewhat laminated, but well suited to quarrying for dimension stone.
2 ft. 8 in.	Consists of hard, laminated rock, occurring in beds from 5 to 8 in. in thickness, between each of which is a very thin layer of shale or clay. These beds are much broken up, and no large dimensions can be quarried.

In the quarries owned by Latham Smith and Frank Hagen the succession of beds is, with a few exceptions, the same as those given above. The stone in the uppermost courses of the Latham Smith quarry is apparently different from that in the other quarries. These courses are very free from impurities, and sufficiently soft to be easily cut and dressed for the finer kinds of constructional work.

Laboratory Examination.

Microscopical Examination.—Thin sections of the limestone from these quarries was examined under the microscope, showing that the stone is thoroughly crystalline, and that the individuals interlock in an intricate manner, suggestive of unusual strength. The stone is essentially calcium carbonate and dolomite, with a very small amount of quartz. (See Plate LXIX., Fig. 2.)

Physical Tests.—The stone from two of these quarries has been thoroughly tested in the laboratory of the Survey, and the results are recorded in the tables in Chapter VIII. The average specific gravity of the stone from the Washington Stone Co.'s quarry is 2.821, the porosity is .43%, and the average ratio

of absorption is .22%. The specific gravity of the stone from the Laurie Stone Co.'s quarry is 2.77, while the average porosity is .59%, and the ratio of absorption .22%. A comparison of these with tests on other limestone shows that the specific gravity is high, and the porosity very low.

The average crushing strength of the samples from the Washington Stone Co.'s quarry, as given in Table II., is 30,737 lbs. per sq. in. on bed, and 30,766 lbs. per sq. in. on edge. The specimens from the Laurie Stone Co.'s quarry tested 31,957 lbs. per sq. in. on bed, and 39,983 lbs. per sq. in. on edge. These compressive strength tests are among the highest obtained for limestone quarried within the state, and are higher by several thousand pounds than the crushing strength of any limestone or marble outside of the state, which has come under the observation of the writer.

The transverse strength tests are given in Table III., and it is also interesting to note that these tests are far above the average. The sample from the Laurie Stone Co.'s quarry gave a modulus of rupture of 4,659.2 lbs. per sq. in., while that from the Washington Stone Co.'s quarry tested 3,923.3 lbs. per sq. in. No limestone is known anywhere outside of Wisconsin which combines such high transverse and compressive strengths. These tests indicate that the stone is well adapted to the purposes for which it is used, namely, breakwater and pier construction.

Samples of the stone from these two quarries were also subjected to alternate freezing and thawing, with the results given in tables VI. and VII. The loss in weight resulting from the test was a very inconsiderable amount, not exceeding .14 of a gram on a mass of 195 grams. From both quarries the crushing strength of the frozen samples averages about 15,000 lbs. per sq. in. less than that of the fresh samples.

Samples of the stone from each quarry were subjected to extreme heat. At a temperature of 800° F. the stratification planes were intensified, and at 1,000°–1,200° F. the samples were partly destroyed through calcination.

Samples which were subjected to the action of carbon dioxide

in a moist atmosphere showed no appreciable deterioration after 44 days' exposure. After treatment by sulphur dioxide, for the same time and under the same conditions, the loss was scarcely appreciable, being only .05 of a gram on a mass of about 50 grams. The samples treated with sulphur dioxide were colored yellow in narrow streaks and irregular patches over the surface. A crystalline precipitate of magnesium salts was also deposited at the surface.

General Considerations.

None of the limestone in this state has given more satisfactory strength and durability tests than the samples from these quarries. But the fact that the laboratory tests are exceptionally high does not indicate that the stone can be profitably quarried for constructional purposes. The stone is hard and refractory, is not easily dressed, and some difficulty is experienced in obtaining large dimensions. These circumstances militate largely against the use of the stone for any purposes where cut stone or large dimensions are desired. As a rule the stone can be used to the best advantage in the rough, or where rock face finish is desired.

The largest demand for this stone at the present time is for rough stone for pier and breakwater construction. It does not pay the quarry owners to assort the stone when quarrying for this purpose, and therefore it is all broken up alike and sold in the rough. Certain of the quarry operators own barges, with which they ship to various markets on the lake. At present the government uses a large amount of this stone, but when this demand is finally supplied, the quarries in this vicinity will be obliged to look to other markets for the sale of their product. The stone is shipped to Racine, Milwaukee, Manitowoc, Muskegon, Michigan City, South Haven, Grand Haven, Frankfort, Traverse City, Kenosha, Escanaba, Manistee, Menominee, Oconto, and many other places. This stone is among the better class of limestones that can be used to advantage for macadam, and it is thought that eventually it will be quarried quite exten-

sively for this purpose. Many of the courses can be used to advantage for building purposes, and where great strength is demanded no better limestone can be used.

The following data summarize the condition of each of the quarries located at this place.

Statistical Data of the Laurie Stone Co.

Average number of employees: 20 to 50.

Wages paid different classes of employees: $1.00, $1.25, $1.37, $1.50.

Cost of transportation: By water, Manistee and Manitowoc $2.00 per cd. Muskegon $3.00.

Shipments for the past five years:

1892, building, 1,637 cds.; footing, 6 cds.; pier, 64 cds.;
1893, building, 1,624 cds.; pier, 1,676 cds.
1894, building, 950 cds.; pier, 1,040 cds.
1895, building, 1,115 cds.; footing, 9 cds.; pier, 820 cds.;
Paving blocks, 111 cds.
1896, building, 277 cds.; pier, 118 cds.;
Paving blocks, 90 cds.; chips, 10 cds.

Statistical Data of the Washington Stone Co.'s Quarry.

Amount of capital invested: $1,200.

Facilities at hand for quarrying: 1 15-hp. engine, 1 hand derrick, 1 steam drill.

Average number of employees: 6 to 45.

Wages paid to different employees: $1.37½ to $1.75.

Cost of transportation: By water, Milwaukee, $2.50 per cord.

Average value of each grade per cubic foot: Building, $.02; pier, $.01⅞; paving, $.03½.

Shipments for the past five years:

1892, building, 1,400 cds.; pier, 400 cds.
1893, building, 600 cds.; pier, 3,840 cds.
1894, building, 400 cds.; pier, 350 cds.; paving, 125 cds.
1895, building, 200 cds.; pier, 350 cds.
1896, building, 300 cds.; pier, 900 cds.

Statistical Data of the Latham Smith Quarry.

Amount of capital invested: $6,000.00.

Facilities at hand for quarrying; 1 hoist engine; 2 steam derricks; 2 hand derricks; boiler; Rand steam drill.

Average number of employees: 70.

Wages paid different classes of employees:

Laborers	$1.25
Quarrymen	1.50

Cost of transportation: By water, Milwaukee, $2.25 per cd.

Average value per cord: $2.50.

Shipments for the past three years:

1894	1,500 cords.
1895	6,000 cords.
1896	5,000 cords.

Statistical Data of the Sturgeon Bay Stone Quarry.

Amount of capital invested: $14,000.00.

Facilities at hand for quarrying: 3 steam drills; 1 engine. 2 hand derricks; 14 cars, and railroad track and engine for handling cars.

Average number of employees: About 65.

Shipments for the past five years:

1892	2,000 cords.
1893	6,000 cords.
1894	2,400 cords.
1895	2,400 cords.
1896	1,800 cords.

MISCELLANEOUS QUARRIES.

A quarry was opened a number of years ago at a station on the Wisconsin Central Ry., in Manitowoc county, known as the Limestone Quarry. The stone has a beautiful white color, is well crystallized, and has a uniform texture. An occasional drusy cavity, often lined with calcite crystals, occurs in some of the beds. The stone is in nowise discolored, and has very much the appearance of white marble. The upper 15 ft. of the quarry consists of stone which is much broken up, which might be used for the manufacture of quicklime. Below the stripping there are from 12 to 15 beds, ranging from 6 to 10 inches in thickness, which apparently contain excellent stone for sills, tables, and coursing. The stone also looks as though it might take a good polish.

At Cooperstown, about 15 miles northwest of Manitowoc, an abundance of Niagara limestone outcrops at or near the surface of the ground. This stone has been quarried to some extent for

the manufacture of lime, and also for local building purposes. It is even grained and has a fine crystalline texture. It varies in color from buff and gray to pink. The upper courses, along the river valley, are considerably broken by jointing planes, but a number of places were observed where the joints were far enough apart to permit of reasonable dimensions being quarried. At other places the joints appear to be relatively close, and indications are less promising. It is quite probable that an abundance of stone suitable for many purposes could be obtained in this vicinity if quarrying was properly conducted.

RÉSUMÉ.

The Niagara limestone furnishes an excellent illustration of the great variety of demands which may be supplied by the stone from a single formation. There is scarcely any purpose for which limestone is used, that is not supplied by the output from this formation. Where the stone is equally suited to a number of uses, it is quarried for that purpose which yields the largest profit. Ordinarily a stone is quarried for the purpose for which it is suited, but it occasionally happens that in view of larger profits a stone is sold for purposes for which it is not adapted.

There seems to be a tendency on the part of quarrymen to prefer to furnish Niagara limestone in the rough, rather than cut. There are several reasons for this, but probably the most important is the much less investment of capital required. Again, the price of skilled labor is much higher than that of ordinary labor, and the margin of profit is very small, especially when the stone cuts with difficulty. For these and other reasons, the limestone of the Niagara formation is used most largely in the manufacture of lime and crushed rock, or sold in the rough for constructional work. Very few of the many quarries in this formation furnish cut stone, but all of them will sell stone in the rough. When sold in this shape it must afterward be cut by the contractor if it is to be used for the finer masonry work.

The stone differs in texture, composition, hardness, color, etc.,

as taken from different beds and from different areas. It is therefore difficult to make any general statement as to the fitness of the stone for any specific purpose from the formation as a whole. It is necessary for one, who desires to know the fitness of the stone from any single area or quarry, to look over carefully the laboratory tests and general descriptions of the quarries given in the main part of this chapter. The formation furnishes, in certain section, excellent building stone. Crude material for the manufacture of many thousands of barrels of lime comes from this formation. In many parts of the state the stone is crushed for macadam. It is used for flux in smelting furnaces. In fact, there are few purposes, for which stone is used, that are not supplied by stone from this formation. The yearly income from this formation is a large item in the productive wealth of the state.

A much larger amount of stone than is now being consumed might be used to advantage for building and other heavy constructional purposes. Thousands of tons of excellent building stone, which ought to be used in the construction of buildings, are each year being broken into crushed rock for macadam. Other stone equally suitable can be obtained for road purposes, and the fine, even textured courses from many parts of the Niagara formation ought to be preserved for the better classes of constructional work.

CHAPTER VII.

AREAS FROM WHICH SUITABLE STONE FOR DIFFERENT USES MAY BE OBTAINED.

BUILDING.

The principal parts of a building into the construction of which stone enters are the foundation and the walls of the superstructure. In a frame building all that portion which is below the first floor is known as the foundation. That part which is concealed beneath the ground is generally random rubble masonry, but that above should be either ashlar or one of the better kinds of rubble walling. The walls of the superstructure of a stone building are either ashlar or rubble masonry. Ashlar walling may be "uncoursed random," "coursed random," "uncoursed squared," "coursed squared," "coursed header," "regular coursed," "dry," or "flint. "Rustic" or "polygonal rag work" is also a form of rubble masonry. "Block in course" is an intermediate class of masonry between ashlar and rubble. Ashlar facing is an expression applied to walls in which stone is used merely as a facing, and is backed with rubble or brick work. The different parts to a building are known by specific names, as "quoins," "window sills," "arches," "window and door jambs," "lintels," "string courses," "corbels," "eaves courses," "copings," "skew corbel," "saddle stone," "cornices," "balustrade," "parapet," "blocking course," "plinth," and "columns." Stone which is used in any of these positions should be carefully cut and dressed, while the necessity for this, in other parts, is not so imperative. The joints in the wall should be close, not exceeding 1-8 or 1-10 of an inch in ashlar masonry. In other kinds of masonry they are often much thicker.

The stone used in ashlar masonry should have the capacity to dress nicely. If the stone dresses easily the wall may be relatively inexpensive, but if the stone is refractory, the expense may be very great. The kind of masonry used also influences the cost. Coursed ashlar is ordinarily the most expensive, on account of the uniformity in height of the blocks. Rubble masonry is expensive in proportion as it approaches ashlar work. Ordinarily there is little attempt to carefully dress the blocks used in rubble masonry, and the joints are often of uneven thickness and roughly finished.

Stone used in special positions in a building should be cut and fitted especially for these positions. Stone used for quoins should be massive and readily dressed. Stone used for window sills and lintels should possess a relatively high transverse strength. Copings and saddle stone should have as few joints as possible. Balustrades, parapets, cornices, and columns should be built out of durable stone which can be cut and carved with good effect. The strength required of the stone depends largely upon its position in the wall. If it is near the base of the wall, the superincumbent load will be greater than if it were near the top, and the strength should be correspondingly greater. At and beneath the level of the ground the stone should be free from parting planes which place the stone in danger from the freezing of any included water.

To find a building stone which meets all of these different conditions perfectly, is not an easy task. A stone that dresses readily may not be as suitable in point of strength and durability, as one that is more refractory. A stone which is in all other respects desirable may contain impurities which will produce unsightly discolorations after a few months' exposure in the wall. Limestone, which is used very extensively in this country for building purposes, is often discolored by iron oxide, bitumen, or efflorescence after it has been in the wall for only a few months.

It would be a difficult task to point out specifically the purposes for which the stone from each quarry in the state is suited.

Likewise, it would hardly be possible for one to indicate all the quarries where stone, suitable for each of the different uses, is to be found. Only in a general way can some of the more important uses and the quarries from which suitable stone may be obtained, be mentioned. For more detailed information, reference should be made to the preceding chapters, in which the quarries are all described individually.

The descriptions in the first part of Part II., Chapter II., concern the granite and rhyolite industry. Granite and rhyolite are the most expensive and difficult stones to work, that are quarried in Wisconsin. The refractory nature of the stone, nevertheless, is one of the indications of its superior strength and durability. The granites quarried at Amberg, Wausau, Montello, and in Waushara county, and the rhyolite from Berlin, are all well suited to masonry construction. These and the Waupaca granite can be worked into magnificent columns, and are admirably suited to indoor work. Only in the more costly structures, is granite used for all parts of a wall. It is most frequently used in the shape of polished columns or corner stones, in buildings constructed mainly out of brick or cheaper stone. Wherever granite is used the strength is ample and the appearance is that of solidity and permanence.

Turning our attention to stone which is more readily worked, we find an abundance, both in kind and quality, which is suitable for constructional work. The Lake Superior brownstone is a material which is adapted to use in all parts of a building. It is cut and dressed with reasonable facility, is strong and durable, and can be obtained in unlimited quantities for blocks or columns of any dimensions. It can be used in all kinds of rubble and ashlar masonry, but is especially adapted to coursed ashlar walling. The stone can be dressed in almost any fashion, but is best suited to rock faced work. Each of the quarries in this district has an abundance of stone for all general building purposes.

The white and buff colored sandstones at Dunnville and Ablemans are the only stones now quarried in the Southern Potsdam area which are well suited to general constructional purposes.

The Dunnville stone is soft and can be easily cut and carved, while the stone from Ablemans is very refractory and difficult to work. The former costs much less than the latter, but is less suitable for permanent and heavy construction.

The St. Peters formation, at Red Rock and Argyle, furnishes a brown sandstone, which is in part suitable for building purposes, mainly rubble masonry. Stone for coursed ashlar walling may be obtained from certain beds in these quarries. The stone has a great variety of colors, and is sometimes built into rustic walls, giving the building a very striking appearance.

The lower Magnesian formation, at Bridgeport, Trempeleau, and Maiden Rock, furnishes stone suitable for all ordinary purposes. The same stone is quarried at a number of other places, mainly for local consumption. Among the latter places are La Crosse and Fountain City.

Stone from the Trenton formation has been used in many parts of the state both for the superstructure and substructure of buildings. It has proven satisfactory for purposes where there is little or no danger from freezing. When the stone is used near the water line it often shells and opens up along the bed. The stone from a number of courses in the Duck Creek quarries is used for building purposes, and as a rule the buildings constructed therefrom have an attractive appearance.

From the Niagara formation at Wauwatosa, Lannon, Genesee, Marblehead, Sturgeon Bay, and Knowles a good quality of limestone is quarried which is generally suited to all building purposes. Fine hammer dressed work on some of this stone is expensive, but the results are as a rule very satisfactory.

From all the formations where quarries are being worked, rough foundation stone can be obtained. Stone from all the quarries is not suitable for foundation walls above ground, which, instead of being constructed from rough stone in random rubble walling, should be built out of ashlar blocks. The appearance of residences and buildings in general would be much improved if the random rubble work, which is suitable only for foundation walls below the surface of the ground, should be replaced with coursed ashlar walling.

The boulders of igneous rock, which are strewn in abundance over certain portions of the glaciated area of the state, furnish a practically unlimited supply of excellent stone, well suited for foundation work, either above or below the ground. Mingling, indiscriminately, the different colored blocks of many shapes and sizes, produces a very attractive appearance. In this work, the joints should be close but the blocks look well with either natural or rough dressed faces.

BRIDGES.

Stone used for bridge work should be heavily bedded, and the joints sufficiently far apart to permit of large dimensions being quarried. The stone should be, as nearly as possible, free from sedimentary planes, with a specially high capacity to withstand the agents of weathering. The stone which most nearly meets these conditions is the heavily bedded Potsdam sandstone from the Lake Superior region, that from Ablemans, and the heavy compact limestone from the Niagara formation at Wauwatosa, Waukesha, Lannon, and Sturgeon Bay. For small culverts and wagon road bridge abutments, suitable stone can be obtained by careful selection from many local quarries. The stone obtained from the local quarries is generally suitable only for random rubble work. Certain of the igneous rocks, although seldom used, are very suitable for bridge work.

RETAINING WALLS.

The stone used in the construction of retaining walls should be as carefully selected as that which is used in the superstructure of buildings. This is not always appreciated, and one often sees a rough and ragged wall where one of beauty should have been constructed. Random rubble work is the most common style of masonry used in the construction of retaining walls. Stone, from any of the quarries in the state, which is not shaly and is free from gross imperfections, may be used to advantage. The brownstone of the Lake Superior region, the limestone of the Niagara formation, and the igneous rocks,

wherever found, if carefully quarried, cut and dressed, are all suitable for retaining walls. Very artistic and pleasing effects are produced by using the different colored boulders of igneous rock, which are scattered in great numbers over the glaciated area of the state. The joints should be especially close in this class of work, to prevent the entrance of water, which often injures the stone by freezing.

MONUMENTAL AND ORNAMENTAL.

Each of the granite quarries furnishes a stone with a different color and texture. Some of the quarries produce two or more kinds, and from each of these quarries, the stone is used for monumental or ornamental purposes. Much of the stone may be obtained either in the rough or dressed, and in any reasonable dimensions.

The brownstone of the Lake Superior region has also been used for monumental work. As an example of such work may be cited the monolith which was prepared by the Prentice Brownstone Company for the Wisconsin exhibit at the World's Fair in 1893. On account of its enormous size, it was never removed from the quarry, and is now being cut up and sold for dimension stone. The base of the monolith was 9 to 10 feet square, tapering at the top to 2½ or 3 feet square. The height was 110 feet, exclusive of base.

But it is among the granite and rhyolite quarries that we must look in the future for monumental stone. They are best adapted to this use. The quarries of Wisconsin furnish granite of almost any desired color or texture, equal in strength and durability to any imported stone.

For inside ornamental work to dwelling houses or public buildings all of the granite is well adapted. The brilliant, coarse, red variety from Waupaca is better adapted to this use than to monumental work, being an excellent material for wainscoting and cylindrical columns. For pillars, columns, and wainscoting there is an abundance of excellent material among the granite quarries throughout the state.

PIER, BREAKWATER, AND CRIB.

For these purposes rough uncut stone is generally used in this state. As a rule, these works are built in a very temporary fashion, without either cement or mortar. The harder limestone, such as may be obtained in the vicinity of Sturgeon Bay and along the bluffs of the Mississippi, and the more indurated sandstone from the Lake Superior region are well suited for this kind of work. The limestone from the quarries at Wauwatosa and adjacent localities, and the granite from the northern crystalline area, are also well adapted for these purposes. Stone is also quarried for these purposes at Grand Rapids, Duck Creek, Neenah, and Menasha.

ROAD CONSTRUCTION.

The suitability of the stone from the different quarries, for purposes of road construction has not been especially considered in this report. It is known that for paving purposes the igneous rocks with smooth heads are most desirable. The limestone blocks used in this state have thus far proven unsatisfactory. The igneous rocks quarried at Berlin, Utley, Montello, Wausau, Granite City, Amberg, and in Waushara county have, on the whole, given the best satisfaction. The quartzite blocks manufactured at Devils Lake, Ablemans, and Portland are very hard and durable, but are objected to on account of the originally rough heads and the slippery surfaces produced after a few years' wear. The limestone blocks may be obtained at a number of quarries, among which those at Lannon are probably the best known. Blocks have also been cut from the limestone at Wauwatosa, Waukesha, Genesee, Racine, and numerous other less important localities.

The most satisfactory material for curbing purposes is obtained from the quarries of igneous rock. The best granite and rhyolite curbing is obtained from the quarries at Berlin and in Waushara county. Nevertheless the largest amount of curbing is supplied by the limestone of the Niagara formation. The quarries at Lannon, Wauwatosa, Waukesha, and Genesee are es-

pecially noted for the excellent limestone curbing which they produce. Curbing is also manufactured from certain of the sandstone quarries, but with the exception of the Lake Superior sandstone it is not placed on the market in sufficient quantity to warrant special mention. The limestone quarries from which the main supply of curbing is obtained also furnish excellent flagging for cross walks and sidewalks.

The largest product of the quarries for road construction is crushed stone. During the last few years a strong sentiment has arisen, favoring good roads. This has been manifest in an increased demand for crushed stone. In many instances this demand has been met by the purchase of good, durable stone, but in other places cheap, undesirable stone has been used. The towns and villages in this state have only begun to use crushed stone in the construction of roads, and now is the time to see that the best material that can be obtained is used. The cheapest and most easily accessible stone is often the dearest in the long run. Keeping in repair, a macadamized road built out of poor material, is oftimes an expensive undertaking. It is far less expensive to use good material when the road is first built. A wagon road which is subject to heavy traffic should be macadamized with a hard, durable stone. Streets that are used only for carriage driving may prove very satisfactory when built out of a softer stone, but a road which is subject to heavy or even moderate traffic should be macadamized with either igneous or metamorphic rock, preferably the former. A road which is subject only to light traffic will prove quite satisfactory if it is built out of the best limestone or dolomite.

The difficulty experienced in the use of limestone arises from the rapidity with which it wears. In the summer, the streets, if not periodically cleaned, have from one to six inches of mud or dust on their surface. The frost in the spring causes them to heave, and thus they are more or less broken up. The roads that are macadamized with igneous or metamorphic rocks wear better than those constructed out of limestone or sandstone, and are less injured by freezing in the spring. The main objection

to quartzite for macadam is the absence of a cementing material by which the fragments should be firmly bound together.

Crushed igneous rock can be obtained at Berlin, Utley, Montello, and Amberg. Crushed quartzite, one of the metamorphic rocks, can be obtained at Devils Lake, Ablemans, and Waterloo. Crushed limestone can be obtained at many places within the state, among which are Wauwatosa, Waukesha, Racine, Janesville, Appleton, Neenah, Menasha, Beloit, Madison, Lannon, Templeton, Duck Creek, and Sturgeon Bay.

MISCELLANEOUS USES.

Hitching posts, monument bases, stepping blocks, etc., are cut from the stone quarried at a large number of quarries in different parts of the state. For hitching posts, there is nothing better than a good solid, well cemented sandstone or limestone. Necessarily, the stone should be free from prominent bedding planes, to prevent any possibility of shaling. Stone suitable for these purposes can be obtained from the Lake Superior region, Grand Rapids, the Saddle Mound quarry, Bridgeport, Waupun, River Falls, Wauwatosa, Waukesha, Lannon, Ablemans, and a number of other places.

RÉSUMÉ.

In general, Wisconsin is exceptionally well supplied with an abundance of stone suitable for nearly all purposes. Slate, onyx, and marble are about the only stones of economic value that are not found. It is unnecessary to import building, monumental, or ornamental stone when equally as reliable stone can be obtained, at the same cost, from quarries within the state. It is to the advantage of the people of Wisconsin to use home products wherever it is possible, for it is through the development of the natural resources that the wealth of the state is increased.

CHAPTER VIII.

DISCUSSION OF THE RESULTS OF THE PHYSICAL TESTS.

Quantitive results, as a basis for estimating the durability of a stone, can only be obtained through a complete series of physical tests. The resistance which a stone offers to compressive stresses, both normal and parallel to the bed, measured in pounds per square inch, the transverse strength in terms of the modulus of rupture, and the modulus or coefficient of elasticity determine the strength of a stone. In many cases the durability of a rock can be estimated from the laboratory examination only when one knows quantitatively the specific gravity, porosity, the effect of extreme heat, the effects of alternate freezing and thawing, and the action of carbonic acid gas and sulphurous acid fumes. The methods employed in performing the tests by which the strength and durability of the building stones, examined in the preparation of this report, were obtained, have been fully described in a previous chapter, Part I., Chapter III., pp. 54–74. Complete tabulated results of all the experiments performed will be found in the latter part of this chapter. The results which are discussed in this chapter have been referred to in the description of the individual quarries throughout the body of this report, and have been compared in a general way with the tests made on building stone from other states. For the purpose of comparison, tables have been compiled (See Tables XI. and XII.) wihch give the results of tests made on building stone from other quarries, in different parts of the United States.

It has been previously noted that, among the sedimentary rocks, the results of tests on samples from different parts of the same quarry may be very different. This difference is sometimes even more marked than that which occurs between samples from different quarries of the same area. It is possible to select samples from a quarry which will stand very satisfactory tests, while the majority of the stone may be of the poorest kind. The most valuable results are those which have been computed for samples which are a fair average of the stone of any particular quarry, and it has been the endeavor, in making the tests from which the following tables are compiled, to represent as nearly as possible the general run of the No. 1 stone, as it occurs in the quarry.

The results of the tests recorded in some reports on building stone are of little value on account of the inaccurate methods employed in making the tests. In computing the results embodied in this report, an attempt has been made to eliminate errors, as far as possible, both in manipulation and computation. The utmost care has been exercised in obtaining truthful results, and it is believed that they are nearly accurate for the samples tested.

CRUSHING STRENGTH.

The individual test which is employed more than any other to determine the adaptability of a stone for different uses is the crushing strength test.[1] This test has been relied upon almost exclusively by certain architects and builders as a criterion of the suitability of a stone for all kinds of public and private buildings. The reason for this is due mainly to the fact that until recent years few other tests have been made. It is very unfortunate that this overestimate of the value of the crushing strength test is still so prevalent, for it should be well known that a stone having a crushing strength of over 5,000 lbs. per sq. inch is strong enough for any modern structure.

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[1] The terms ultimate strength, compressive strength, and crushing strength are used interchangeably in this report, and refer to the maximum load sustained by the sample in question, unless otherwise stated.

The crushing strength of the more important building and ornamental stones of Wisconsin is given in Table II., at the close of this chapter. To be assured of the reliability of these tsets, in a number of instances samples from the same quarry were crushed in two different Riehle testing machines, one of 100,000 lbs. and the other of 300,000 lbs., and also in a 50,000 lb. Olsen machine. A comparison of these results showed that the three maschines correspond very closely. But in order to be certain that the machines were reading correctly, the 100,000 lb. machine of the University of Wisconsin was calibrated, with the result given in Table I. The calibration shows that the machine reads up to 80,000 lbs., as far as it was calibrated, with a very small error, not sufficient to be taken into account in the results. It is thought that above 80,000 lbs. there is little possibility of error in the machine, and we can very safely assume that all readings are nearly correct. A large percentage of the tests were made with this machine, but the stronger samples were crushed in the 300,000 lb. machine at Purdue University, Lafayette, Ind.

The first part of Table II. records the results of the tests made on granite and rhyolite. The second part gives the results of the tests on limestone cubes, and the last part contains the results of the tests on sandstone cubes. In this table there is given the name of the quarry, the location, the average area of the bearing faces, the weight at which the first crack was made, the ultimate strength of the sample, and the ultimate strength in pounds per square inch. In the column under Remarks, the manner in which the sample broke is recorded. None of the granite samples were laminated, with the exception of those from Jenk's Quarry at Irma. The Berlin rhyolite has a rift and run, which correspond to a lamination. In crushing these samples with strongly developed structures, note was taken of their position with reference to the direction of pressure.

Granite and Rhyolite.—The crushing strength of the granite and rhyolite quarried in Wisconsin is very high, none of the tests falling below 12,000 lbs. per sq. in. The average crush-

ing strength of the igneous rocks, computed from the total number of tests made, is between 26–27,000 lbs. per sq. in., while the maximum strength recorded was 47,674 lbs. per sq. in. The minimum crushing strength is equal to the maximum crushing strength obtained for the sandstone, while the maximum is the highest yet recorded for any rock. This maximum crushing strength of over 47,000 lbs. per sq. in. was obtained from a sample of the Berlin rhyolite, on which the pressure was applied normal to the head. That the crushing strength was higher in this than in either of the other directions was a matter of some surprise. It has always been supposed that the crushing strength of a stone is higher across the bed than on the edge, but apparently this is not true in the case of the Berlin rhyolite. The rhyolite is a rock which is apparently composed of flattened rods, forming what one might consider a very compact bundle. Greater pressure can apparently be transmitted along these bundles of fibers, without injury, than can be transmitted across them.[1]

When one observes a polished face of the rock, he will notice that the elongated feldspar crystals are fractured across the long direction. These small, scarcely perceptible fractures may be one of the causes for the greater readiness with which the rock crushes normal to the rift or run.

The Montello granite has a crushing strength of nearly 44,000 lbs. per sq. in., which, so far as my knowledge goes, is the highest crushing strength that has been recorded for any granite. It exceeds the highest test on the Fourche Mountain granite[2] of Arkansas by nearly 15,000 lbs., while the highest test of the granite from St. Cloud, Minnesota, is less by about 16,000 lbs.

[1] An elaborate macroscopic and microscopic description of this rhyolite by Samuel Weidman, is to be found in Bulletin No. 3, of the Wis. Geol. & Nat. Hist. Survey.

[2] Comparison is made with the Fourche Mountain granite in view of the fact that J. Francis Williams, in his report on the Igneous Rocks of Arkansas, considers that rock "to be considerably stronger than any true granite yet tested." See Ann. Rept. Arkansas Geol. Survey, 1890, Vol. II. p. 42.

per sq. in. The granite from Waushara county, Wisconsin, gave a crushing strength test of over 36,000 lbs. per sq. in., which exceeds the highest test made on the Fourche Mountain granite by 7,000 lbs. per sq. in. Thus it is seen that, from at least three different areas in Wisconsin, granite and rhyolite can be procured, which have a crushing strength which, as far as known, exceeds the highest results that have yet been obtained upon granite from any other quarry in the United States.

The rhyolite quarried at Berlin is probably one of the strongest rocks in the world, irrespective of the direction in which the pressure is applied. It is so strong that it could be placed with safety at the base of a monument thirteen times the height of the Washington Monument, if a factor of ten is sufficient for safety. Where a single column or block is required to support a heavy mass of superstructure, there is no stone better fitted than this, or the Montello or Waushara granite. The Montello and Waushara granites are almost equally as strong as the Berlin rhyolite, and there has been no structure yet built into which either could not have been placed with perfect safety.

The granite from Amberg, Wisconsin, either the Athelstane or the Pike River gray, is above the average in crushing strength. The Wausau granite has a maximum crushing strength of over 27,000 lbs. per sq. in. corresponding very nearly in strength with that from St. Cloud, Minnesota. The granites from Irma, Granite City, and High Bridge, all gave maximum crushing strength tests of over 20,000 lbs. per sq. in.

As has been previously indicated, a number of the samples tested, were poorly prepared. Owing to this circumstance, when placed under pressure, they broke off or scaled off on the sides or corners before the ultimate strength was reached. Wherever this occurred, the area of the bearing faces was proportionately decreased, and the actual crushing strength is considerably above that recorded in the tables. Most of the granite samples broke with an explosion, which generally powdered all but the upper pyramid. In a few cases the lower pyramid remained intact, but, as a rule, it was almost, if not quite destroyed. In the

case of the granite, the so-called pyramids are not literally pyramids, but rather cones, in which a concentric structure, resembling cleavage, has been developed. The shape of the cones is nicely illustrated in the Plates L. and LI. The rhyolite sample, which gave the record test, was completely powdered, with the exception of the small cone which is shown in Plate LIV., Fig. 5.

Limestone.—The second part of Table II. is a record of the ultimate strength and crushing strength in lbs. per sq. in. of samples from the important limestone quarries in Wisconsin. By glancing down the column in which the crushing strength in lbs. per sq. in. is recorded, it is observed that not only does Wisconsin have exceedingly strong granite and rhyolite but she also has dolomitic limestone which surpasses in strength any known limestone, dolomite, or marble in the United States. The samples of limestone which gave the highest crushing strength tests were obtained from the Marblehead Lime and Stone Co.'s quarry. Two samples were tested from this quarry one of which gave a result of 42,787 lbs. per sq. in. on bed, which is nearly 18,000 lbs. higher than any known tests recorded for limestone, dolomite, or marble in the United States. The other sample gave a result of 40,453 lbs. per sq. in. *on edge,* which is only about 2,000 lbs. less than the crushing strength of the sample tested on the bed. But the limestone from this quarry is not the only one which is remarkable for its compressive strength. The samples from the Laurie Stone Co.'s quarry, at Sturgeon Bay, gave a crushing strength of nearly 40,000 lbs. per sq. in. *on edge,* and 31,957 lbs. per sq. in. on bed. The samples from Lee Bros.' quarry at Genesee gave a maximum crushing strength of 36,700 lbs. per sq. in. on bed. Those from the Washington Stone Co.'s quarry at Sturgeon Bay gave a maximum crushing strength of 31,800 lbs. per sq. in. on bed; the stone from Bauer's quarry at Knowles tested over 32,000 lbs. per sq. in. on edge; and that from the Menominee Falls quarry, at Lannon, has a maximum crushing strength of over 33,400 lbs. per sq. in. Among the other limestones which tested 20,000

lbs. per sq. in., or over, may be mentioned those from the Gillen Stone Co.'s quarry at Duck Creek, and the Wauwatosa quarries, near Milwaukee. The stone from the Waukesha Stone Co.'s quarry should probably be included here, but failure to send to the Survey the material for the tests accounts for the stone not having been tested.

It is not one of the necessary requisites of building stone that it should have such an enormous crushing strength, but it is interesting to know that Wisconsin is provided with stone which will withstand exceptional compressive stresses, and is suited for uses where exceptional strength is demanded.

The lowest crushing strength test obtained for limestone was a little over 6,600 lbs. per sq. in., which is exceeded by but few sandstones from this or adjacent states. The maximum test obtained on samples from this same quarry was over 10,000 lbs. per sq. in. The enormous crushing strength of the stone from Sturgeon Bay, Marblehead, and Genesee is evidence that the Niagara limestone is especially well adapted for use not only in heavy buildings, but also in the construction of piers, breakwaters, and roads.

The samples of limestone generally broke more quietly than the granite. Occasionally they would scale off along the edges and corners before the maximum load was applied. Sometimes, two fairly well developed pyramids remained, but, as a rule, in the more carefully prepared samples only the upper one was to any extent perfect. The pyramids which remained were ordinarily much steeper and more slender than those of the granite, and occasionally they developed into wedge-like forms, resembling somewhat the wedge-shaped pyramids of the granite. Often the sample was much splintered, even the pyramid falling in pieces when raised from the steel plate. The cone which remained after the record sample of limestone was crushed is shown in Plate LIV., Fig. 6. Other pyramids are shown in the same plate, and in Plates LII. and LIII.

Sandstone.—In the third part of Table No. II. is recorded the results of the crushing strength tests on two inch cubes of sand-

stone. The samples which were tested are mainly from the brownstone quarries of the Lake Superior region, although tests of the Southern Potsdam and the St. Peters sandstone will also be found in the table. None of the results can be considered especially high, although many of them compare favorably with tests made on stone from quarries in other states. The sandstone from the C. & N. W. Ry. Co.'s quarry at Ablemans tested 13,669 lbs. per sq. in., which is the maximum compressive strength for sandstone from this state. The other tests range all the way from this down to 2,000 lbs. per sq. in., and in several instances, where the samples have been unsatisfactorily prepared, the results are even lower. The results of tests on the Lake Superior brownstone show that it is considerably stronger on the bed than on the edge. This observation may also be made with reference to the white and brown sandstone from other parts of the Potsdam and from the St. Peters formation.

The average compressive strength of the Lake Superior brownstone is somewhat higher than that recorded for the Bedford limestone of Indiana, as given on page 317 of the 21st Annual Report of the Indiana Department of Geology and Natural Resources. The average crushing strength of seventeen cubical specimens of Bedford limestone is here given as 4,326.7 lbs. per sq. in. The average of twenty tests of Lake Superior brownstone, half of which were made on edge and the other half on bed, was 4,816 lbs. per sq. in. As near as can be ascertained from the tests that are scattered through the various reports, this strength is equal to, or above that of the red sandstone from northern Michigan. I have been unable to find any series of crushing strength tests of the Connecticut brownstone which would warrant making comparisons, but it is believed that the Lake Superior sandstone is equally as strong as the eastern brownstone.

The softer the sandstone, and the more rounded and uniform the grains, apparently the more perfect are the pyramids. In the stronger samples the ordinary pyramidal result gives way

partly to the conical. An occasional wedge-shaped piece resuleted from the breaking, but this form is not so common as in the granite and limestone samples.

General Considerations.—In general, the crushing strength of the stone from the different quarries in Wisconsin, when compared with the results obtained for other building stones in the United States, (See Table XII.), shows some surprising results. We learn, here, for the first time, that the granite, rhyolite, and limestone are in several instances unsurpassed in strength by any known stone, similar in kind, in the United States. Our attention has also been called to the fact that the difference between the crushing strength on bed and on edge, in the weaker rocks, is considerably greater proportionally than it is in rocks which are very strong. The highest compressive strength of samples from the same limestone quarry, was in several instances obtained from cubes placed on edge. Attention has been called to the fact that the Berlin rhyolite, the strongest stone tested, has the greatest strength when pressure is applied in the direction of the rift. These examples indicate that there are exceptions to the general rule that the greatest compressive strength is obtained when pressure is applied normal to bedding. It appears that this rule holds good for stone with a low compressive strength, but when the compressive strength is very high, the reverse is fully as likely to occur. It may even prove the rule.

The manner in which the stone breaks also indicates to a greater or less degree the strength of the stone. Crushing a stone which has a compressive strength of less than 10,000 lbs. per sq. in. usually results in two quite well defined pyramids. A stone which has a compressive strength of between 10,000 and 20,000 lbs. per sq. in. seldom results in pyramids as perfect as those which result from crushing cubes of less strength. In this stronger class of stones the pyramids are often wedge-shaped, but are more generally intermediate between a pyramid and a cone. Crushing samples having a compressive strength

of over 20,000 lbs. per sq. in. generally results in only one pyramid, with more of a conical than pyramidal outline. When a stone reaches a crushing strength of over 30,000 lbs. per sq. in., the breaking results in the production of a single small upper cone. There is developed in the granite, and in some of the sandstones and limestones, a parting structure, similar to that which occurs in the granite samples illustrated in Plate LI. This concentric structure is also nicely shown in Plate LII.

It should be noted that the conical and not the pyramidal shape is the natural one. The reason for obtaining pyramids in crushing the weaker rocks is due to the control exerted by the square faces of the cube.

TABLE.—*Showing the difference in crushing strength through interrupted pressure.*

NAME OF QUARRY.	CRUSHING STRENGTH.		Remarks.
	100,000 lb. machine.	300,000 lb. machine.	
Pike River Granite Co.	25,000	27,887	Most of these samples were chipped when placed in the second machine.
New Hill O'Fair	25,000	27,262	
Milwaukee Monument Co.	25,000	38,063	
Leuthold Quarry	25,000	20,875	
Washington Stone Co.	27,855	29,526	
Gillen Stone Co.	25,000	20,308	
Gillen Stone Co.	24,783	14,869	

No data are thus far available from which one can glean any knowledge of the effect of long continued pressure below the point of rupture on the strength of the rock. Neither have data been obtained indicating the effect of intermittent stresses on the rupturing of rocks. In making the compressive strength tests in the preparation of this report, a number of samples were placed in the 100,000 lb. Riehle testing machine, which could not be crushed. These samples were removed, and afterwards

crushed in a 300,000 machine, with the results indicated in the accompanying table. The apparent loss in strength in some of the samples cannot be entirely attributed to the intermittent character of the pressure. It is probably due, to some extent, to the fact that the samples were chipped at the corners and edges when in the first machine. These and other causes incident upon a change of machines may partially account for the losses, but, nevertheless, the results would seem to indicate that an actual decrease in strength is occasioned by continued or intermittent pressure below the ultimate strength. Further experiments along this line are needed.

TRANSVERSE STRENGTH.

The strength test which is next in importance to a knowledge of the compressive strength of a stone, is the transverse strength. The transverse strength is indicated by the modulus of rupture, which is determined after the method described on p. 62.

The transverse strength is valuable in estimating the thickness required of stone when supported only at the ends, as in the case of lintels, sidewalks, cover stones for culverts, etc. Some stones in these positions will support a much greater load than others, and the only way to ascertain the capacity of different stones to support loads when in these positions is to determine experimentally the modulus of rupture.

Granite.—The modulus of rupture of only two granites was determined in the preparation of this report. (See Table III.) Each of these gave a result of over 2,300 lbs. per sq. in. The modulus of rupture of the Wausau granite averaged about 2,400 lbs. per sq. inch, while that from Montello averaged about 3,780 lbs. per sq. in. The samples broke suddenly, and the fracture extended diagonally across the center of the piece. There is no doubt but that the modulus of rupture of most of the granites of this state will either equal or exceed the results obtained in these tests.

Limestone.—The limestone was more generally tested than the granite, and gave results ranging from 1,164 to 4.659 lbs. per sq. in. The latter result was obtained from samples of stone from the Laurie Stone Co.'s quarry at Sturgeon Bay. This result is very high, being greater than that obtained for either of the granites. Tests made on samples from the Marblehead Lime and Stone Co.'s quarry gave a modulus of rupture of 3,632 lbs. per sq. in. All these samples broke very close to the center, and much quieter than the granite.

Sandstone.—The transverse strength of the sandstone is very much lower than that of either of the two preceding kinds of rock. The maximum modulus of rupture was obtained from samples of the stone from the C. & N. W. Ry. Co.'s quarry at Ablemans. One of these tests gave a modulus of rupture of 1,324 lbs. per sq. in., which is above the average result for sandstone of this character. The tests made on samples of sandstone from the Lake Superior region gave a much lower modulus of rupture. Eight tests gave an average result of about 500 lbs. per sq. in. This is somewhat less than is required for a stone used as caps or sills in heavy buildings, but is thought to be sufficient for all ordinary construction provided stone of considerable thickness be used. The necessity for using a stone with a high modulus of rupture is now often avoided by arching the doors and windows. All stone having the characteristics of the Lake Superior brownstone possesses a less transverse strength than the more compact and harder rocks, such as the Niagara limestone.

MODULUS OF ELASTICITY.

The modulus of elasticity has been obtained for but few of the building stones in the United States. Many of the state reports have entirely omitted this from their series of tests.

A knowledge of the modulus of elasticity is valuable to architects and builders in calculating the effect of loading a masonry arch, or proportioning abutments and piers of railroad bridges, subject to shock, etc.

In obtaining the compressive strength of the different samples

tested in the preparation of this report, the compression was obtained for increments of from 500-1,000 lbs. pressure. These results were recorded, and from them the modulus of elasticity was computed as explained on p. 63. In obtaining the compressive strength, thin sheets of blotting paper were placed between the bearing faces of the cube and the steel plates, for the purpose of distributing the load evenly. It is quite evident that the use of the blotting paper vitiated to a greater or less degree the compression results obtained. Specifically, this is due to the greater compressibility of the blotting paper over the stone. In order to compensate for the blotting paper, no readings were taken until the total load was above 1,000 lbs. This naturally eliminated to some extent the total error, although it is thought that the results are still considerably lower than they would have been had the bearing faces of the samples been placed in direct contact with the steel plates.

Granite.—In the case of the granites, the results range all the way from 150,000 to 2,000,000 lbs. per sq. in. (See Table IV.) The latter result is very high, while the former is comparatively low. The granite from Wausau gave a quite uniform result of about 1,000,000 to 1,500,000 lbs. per sq. in. The Athelstane granite approximated very close to 1,000,000 lbs. per sq. in., in one instance exceeding that figure, and in two others falling a few thousand pounds short. The Pike River gray granite has a modulus of elasticity of about 1,500,000. The Waushara granite tested about 600,000, while that from Irma and High Bridge, each averaged about 500,000 lbs. per sq. in.

Limestone.—The modulus of elasticity ranged all the way from 1,835,000 to 31,500 lbs. per sq. in. The limestone from Sturgeon Bay gave a result of about 700,000, while the result of the tests on the Duck Creek limestone was about 462,000 lbs. per sq. in. The stone from the Waukesha Stone Co.'s quarry, tested by Fuldner and McDonald, gave an average of about 1,250,000 lbs. per sq. in.

Sandstone.—The modulus of elasticity of the sandstone is very much lower than that of either the granite or limestone.

The highest result was obtained from samples of the white sandstone from the C. & N. W. Ry. Co.'s quarry at Ablemans, which tested 400,800. The samples from the other quarries range from this down as low as 32,000. The modulus of elasticity of the Lake Superior brownstone ranges all the way from 56,000 to 387,900 lbs. per sq. in.

It will be observed that in a general way the modulus of elasticity corresponds with both the crushing and the transverse strength of the various rocks. We have seen that both the crushing and transverse strength were lowest for sandstone, and, similarly, the sandstone has the lowest modulus of elasticity. On the other hand, it has been pointed out that the crushing and transverse strength are very high for the granites and limestones, all of which give correspondingly high results for the modulus of elasticity.

SPECIFIC GRAVITY, POROSITY, RATIO OF ABSORPTION, AND WEIGHT PER CUBIC FOOT.

The results of these tests are all largely interdependent. A relatively high specific gravity will naturally increase the weight of the rock per cubic foot, while a high percentage of pore space will accordingly decrease the weight. The percentage of pore space and the ratio of absorption are both dependent upon the amount of water which the rock will absorb.

Specific Gravity.

By referring to Table V., in which these results have been tabulated, one will notice that the specific gravity of the granite from the different quarries is very nearly the same. This is true of the series of limestone and sandstone samples, in each of which the specific gravity is nearly the same. For example, the average specific gravity of the granite is 2.655. The minimum is 2.629, and the maximum is 2.713. The average specific gravity of the limestone is 2.808, the minimum is 2.740 and the maximum is 2.856. The sandstones have an average specific gravity of about 2.631, with a minimum of 2.524 and a maximum of 2.660. It will be observed that the

iron, which is the cause of the color of the brownstone of the Lake Superior region, is not present in sufficiently large quantities to increase perceptibly the specific gravity. The specific gravity of the Lake Superior brownstone does not exceed very greatly the sandstone of the Southern Potsdam area, in which the percentage of iron is apparently very much less. The specific gravity of the granite is largely influenced by the percentage of ferro-magnesian minerals present, as exemplified in the case of the Athelstane granite from Amberg, which has the maximum specific gravity of all the granites tested.

An admixture of siliceous material apparently decreases the specific gravity of limestone. The highest specific gravity is obtained from the most compact and finely crystalline dolomite. In this connection, it is interesting to note that the stone from the Marblehead Lime and Stone Co.'s quarry has the highest specific gravity of any sample tested in the preparation of this report. This immediately suggests that there may be some relation between the specific gravity of a rock and its crushing strength. However, this is only a coincidence, because only with reference to stones with like chemical composition, such as limestone and dolomite, could this possibly be true. Between granites, this relation does not hold, for it is shown in the table that granite having a high specific gravity often has only a medium crushing strength. The crushing strength is dependent upon other factors, such as fineness and compactness of the individual grains, and, as a rule, has no correspondence with the specific gravity. Likewise, there is apparently little, if any relation between the specific gravity and the porosity or ratio of absorption of a rock.

Porosity and Ratio of Absorption.

On previous pages of this report, (See pp. 68–69) a distinction has been made between porosity and ratio of absorption. Porosity has been defined as the percentage of actual pore space in a rock, while the ratio of absorption has been taken as the percentage of the weight of the absorbed water to the average

weight of the dry sample. A glance at Table V. indicates that there is no definite relation between the porosity and the ratio of absorption, although, in a general way, it may be said that the porosity is a little more than twice the ratio of absorption. The fluctuation in the ratio between the two depends largely upon the specific gravity of the different rocks. Very few of the samples from quarries within this state have a ratio of absorption exceeding 10%. The ratio of absorption of the brownstones of the Lake Superior region ranges all the way from $4\frac{1}{2}$% to 11%.

It has been customary to look with suspicion upon a rock which absorbs more than one-tenth of its weight of water. But it has been previously shown, (pp. 20–23), that the danger from freezing and thawing is not so much dependent upon the percentage of water absorbed as upon the size of the pores in a rock. A rock may have a ratio of absorption of 15% or even 18% and yet never be in danger of freezing, on account of the rapidity with which it gives off its included water. The amount of water which a rock will absorb has very little relation to the liability of injury from freezing and thawing, in the case of building stone. Thus, none of the pores of the brownstone from the Lake Superior region are minute enough to retain the water which may collect in them, sufficiently long to allow freezing and thawing to injure them materially.

It is on account of the large size of the pores, through which the water is given off with reasonable rapidity, that we can cite numerous instances of where the brownstone has been quarried and laid in walls during the cold winter months *without injury.* On the other hand, J. P. Merrill, in the report on building stones in the 10th census, refers especially to marble and limestone, which have a low porosity, as being susceptible to injury by hard freezing immediately after being quarried.

In no printed report have I yet been able to find laboratory determinations of the actual pore space of the building stone tested. It appears that the determination of the pore space or porosity is far more important than the ratio of absorption, and ought to replace it among the physical tests of building stones.

The ratio of absorption means nothing with respect to the character of the rock itself, and does not give one an accurate idea of the proportion of the rock which is pore space.

It will be observed by referring to Table V. that the actual porosity of one of the sandstones tested reaches as high as 28.28%, which is near the theoretical maximum limit of pore space. From this high percentage they range all the way down to 4.81%. A larger part of the brownstone has a porosity of 19–20%.

Limestone is much more compact than sandstone, and therefore the porosity and ratio of absorption are very much less. Among the limestones, those that are arenaceous have the highest porosity, reaching in one instance 13.36%. In this sample, the ratio of absorption is only 5.60%, which is well under the 10% limit. The porosity of the limestones ranges from this down as low as .14 of 1%. We note in this connection that the stone from the Marblehead Lime and Stone Co.'s quarry contains about .71 of 1% pore space, being one of the three limestones showing less than 1% pore space.

None of the granites have a porosity which exceeds one per cent. Most of the samples tested had a porosity of about .45 of 1%, which indicates the exceeding compactness of the grains, and the minute character of the pore spaces. Owing to the interlocking character of the grains, the pores of the granite are much smaller than those of arenaceous limestone, and the water is, therefore, retained with correspondingly greater tenacity.

The walls of a building constructed out of sandstone seldom become thoroughly saturated with water, although they may be wetted by the water of imbibition which adheres as a film to the individual grains and is thus conducted through the body of the wall. It appears that a rock with pores of capillary size cannot be completely saturated with water to any considerable distance above the water line, until the entire mass of stone contains its full amount of water of imbibition. If a stone with capillary pores is saturated at one point with water and the supply discontinued, it remains so only for a very short time, owing to the

fact that the water is not only given off at the surface and at the base of the wall, but through capillarity is quickly distributed through the entire mass. When the water of imbibition freezes in a stone, in which the pores are of capillary size, it can occasion no injury to the stone.

Rocks which are exceedingly well compacted without respect to the size of the grains not only have a small percentage of pore space, but also have pores of very small size. Many of the pores in the granites and some of the limestones are certainly of not more than sub-capillary size. The pores in rocks of this character, when containing water, must be, theoretically, filled. It is more difficult for the water to penetrate a rock in which the pores are of this size, but when once it has made an entrance, it is vastly more difficult to expel it. Continued rains will fill a great many of the sub-capillary pores of a rock along the exposed surface, although the water may never penetrate through the block. And it must be remembered that the greatest damage is done when the water freezes in pores that are *filled.* If they are near the exposed surface, the danger from injury will be much increased. It is not necessary that all parts of a stone with subcapillary pores be saturated in order to suffer harm from freezing. If the water penetrates the rock for one or two inches below the surface, this will probably be sufficient to occasion the maximum limit of injury. If freezing should immediately follow precipitation, it is hardly probable that, in a stone with capillary pores, it would reach that depth before the capillary water had been dissipated and the stone placed out of danger.

From the above it can be plainly seen that a wall built of granite or other stone, in which the porosity may be very low, but the pores of subcapillary size, is in as great, or greater, danger from alternate freezing and thawing as a wall built of sandstone or other rock having a porosity of 10 or even 15%, but in which the pores are of capillary size. In the case of monuments, there is greater possibility of sandstone becoming saturated than when used in any other position above ground, but even here the liability of danger from freezing is small.

It must be understood that the above discussion does not apply to shaly sandstone, or other laminated stone, between the layers of which water may collect more rapidly than it can be carried off through the pores. Water thus collected does great damage to a stone by freezing. Such water cannot be considered under the head of water contained in the pores, and yet it may be pointed to as the main cause of the shaling of many of the Connecticut and eastern brownstones.

The above explains, in a large measure, the permanence of sandstone walls over granite and limestone, as observed in many of the larger cities of this and adjacent states.

In Table XI. will be found the specific gravity and ratio of absorption of building stone from quarries in different parts of the United States. This table has been compiled from various sources, and is inserted for comparison with the results in Table V.

Weight per Cubic Foot.

It is sometimes important to know the weight of the stone from different quarries. It is impracticable to attempt to give the weight of the stone if it contains an indefinite amount of water, as it does when first taken from the quarry. The last column of Table V. gives the weight of a cubic foot of the dry stone from each of the quarries for which the specific gravity and porosity of the stone were determined. The stone which weighs most per cubic foot is that from the Marblehead Lime & Stone Co.'s quarry. The weight of this stone averages 176.6 lbs. per cu. ft. The lightest stone is the sandstone from the Dunnville Sandstone quarry, which weighs 115.55 lbs. per cu. ft.

The sandstones range all the way from 115.55 to 148.3 lbs. per cu. ft. The limestones range from 153.69 to 176.06 lbs. per cu. ft. A majority of the limestones weigh from 165 to 175 lbs. per cu. ft. The maximum weight of the granite was obtained for the Athelstane from Amberg, which averaged 168.5 lbs. per cu. ft. The granite from the L. S. Cohn Granite quarry at Granite Heights gave the minimum weight, which was 163.29 lbs. per cu. ft. All of the granites weigh within 5

lbs. per cu. ft. of one another, and have an average weight of 164.98 lbs. per cu. ft.

FREEZING AND THAWING TESTS.

Very few tests have thus far been made to determine the result of alternate freezing and thawing upon building stone. The importance of such experiments has never been questioned, but the difficulty involved in manipulation and the many conditions which must be considered before drawing conclusions from the quantitative results, have apparently had the effect of almost excluding these determinations from the reports on building stone. In the following discussion, for brevity, the samples which were not subjected to alternate freezing and thawing, have been termed the *fresh* samples. Those which have passed through the process of alternate freezing and thawing have been designated the *frozen* samples.

The effects of alternate freezing and thawing may be manifested in three ways: (1) cracks may form, (2) small particles or grains may be thrown off from the surface, occasioning a loss in weight, (3) the strength of the samples may be very much lessened. The first case is seldom observed in the small samples tested, owing to the fact that the stone is generally so carefully selected that no incipient joints are present.

Loss in weight.—Occasionally the weight of a sample will be lessened by small particles being shoved off from the surface by the frost. Where incipient joints occur small flakes are, also, sometimes removed by the pressure of the freezing water. Sandstone which has been sawed or hammer dressed usually has a great many grains on the exterior, which are partly loosened from the matrix. These are ready to fall away from the mass through a very small pressure, which is fully supplied by the freezing of the water which fills the cracks already made in the cement. These loose particles over the surface of the sample are naturally much more abundant in the case of sedimentary rocks, such as sandstones, than they are in the case of igneous rocks or finely crystalline limestone. It is very apparent that the loss in weight will depend mainly upon the manner in which

the samples have been dressed, and the kind of stone. Alternate freezing and thawing for a period of 35 days will result in scarcely more than the removal of the loose grains or fragments from the surface, and any loss in weight occasioned thereby does not indicate the extent to which the stone has been injured. If the process were continued over a very much longer period it is very probable that additional loss in weight would occur, but even this would not express the comparative injury to different kinds of stone.

All the tests thus far made in the preparation of building stone reports of other states that have come to my notice have resulted simply in the determination of the loss in weight, which I consider to be of comparatively little value in estimating the durability of the stone.

The loss in weight due to alternate freezing and thawing was determined for the stone from all the more important quarries in this state. These results are given in Table VI. The manner in which these tests were performed is carefully explained on pp. 70–72, from which it will be observed that the samples were subjected to the severest possible conditions. A glance at the table shows that the loss in weight of the granite and rhyolite did not exceed .05 of 1% on a mass of about 350–360 grams. In the case of the limestone the loss did not exceed .3 of 1%, being, as a rule, less than .1 of 1%. The loss on the sandstone samples was somewhat greater than the limestone, but did not exceed .62 of 1%, with an average of about .14 or .15 of 1%. Such losses in weight are almost insignificant, and are valuable mainly in showing that the more loosely compacted sandstones have more of the grains on the exterior loosened in the preparation of the samples than the more compact granite, rhyolite, or limestone It is very probable that had these samples been subjected to another 35 days' exposure similar to the first, there would have been much less difference in the loss of weight between the samples of granite, limestone, and sandstone. There is no doubt in the case of the sandstone, but that the loss in weight is due largely to the loosening of the individual grains at the surface, in the preparation of the samples, and it is probable that the loss

in weight recorded for the granite and limestone is also largely due to this cause.

Loss in Crushing Strength.—Lastly, the result of alternate freezing and thawing is manifest in a decrease in the crushing strength of the rock. It is quite evident that if a stone is saturated with water and allowed to freeze, and the process be repeated a score or more of times, that the adhesion of the particles will be weakened and the cement perhaps shattered or broken. This will not necessarily occasion any immediate loss in weight, although it is evident that the rock will lose in strength. Thus far I have been unable to find any experiments which show quantitatively the result of alternate freezing and thawing on the crushing strength of different building stones, yet is quite apparent that this is one of the most important tests in determining the weathering properties of building stone. In Table VI. is given the crushing strength of the samples of granite, limestone, and sandstone, which were previously subjected to alternate freezing and thawing, as described on pp. 70–72. In Table VII. the crushing strength of the fresh samples is compared with the crushing strength of the frozen samples. In the last column of this table, No. VII., the difference in the crushing strength of these samples is given. The figures that are in parenthesis indicate the increase in strength of the frozen over the fresh samples, while the others give the loss in strength of the frozen over the fresh samples.

In order to interpret correctly these results, it is necessary that one understands the character of the individual samples used in performing the tests. Unfortunately some of the limestone samples used in the freezing and thawing tests were prepared with less care than those used in the crushing strength tests. In some cases this accounts in part for the difference in strength recorded in the table. Wherever outside conditions have influenced the results, they have been indicated in the column under "Remarks." They have also been referred to in the description of the individual quarries.

Most of the granite samples were carefully prepared, and the results show considerable uniformity throughout the entire

series of tests. In the case of the Pike River granite, allowance must be made for the shape of the samples used. The bearing faces were parallel and smooth, but the other faces were somewhat rough and irregular. The same may be said of the samples from the Berlin Granite Co.'s quarry. It will be observed that the crushing strength of the frozen samples of red granite from the Pike River Granite Co.'s quarry, and the samples tested from the Berlin Granite Co.'s quarry are higher by 4,000 and 11,000 lbs., respectively, than the crushing strength of the fresh cubes. These differences may be largely attributed to the way in which the cubes were prepared. A number of the samples of the granite, as well as limestone, were sawed from large blocks. The sawed surfaces were rough, owing to the shifting of the saw as it followed the softer parts of the rock. This shifting was sometimes as much as an eighth of an inch. The bearing faces were ground down until they were smooth and parallel, but the vertical faces were left in the irregular shape in which they came from the saw. Thus it is seen that the actual area of the bearing faces may be above or below that computed, which would admit of a possible error in computing the strength.

In the case of the limestone, the samples from the Washington Stone Co.'s quarry and from the Laurie Stone Co.'s quarry, used in the freezing and thawing tests, were also somewhat roughly prepared, which accounts, in part at least, for the apparent great loss in crushing strength. The frozen samples from the Gillen Stone Co.'s quarry gave a higher crushing strength than either of the fresh samples, which was due to the fact that the fresh samples were placed under a pressure of 100,000 lbs., and then removed to a machine of greater capacity, on account of which they were crushed with a load considerably under the actual crushing strength of the stone. The fresh samples which were tested from Story Bros.' quarry were hammer dressed, and therefore the results are much lower than they otherwise would be. The sample used to determine the effects of freezing and thawing was sawed, and the result is therefore much higher and nearer the actual crushing strength of the rock.

In the case of the sandstone, all of the samples used in per-

forming these tests, with one or two exceptions, were as carefully prepared as the fresh samples used in determining the crushing strength. They consequently show results which are, as a whole, more uniform than those of either the limestone or granite. Samples from the Grover Red Sandstone Quarry, used in the freezing and thawing tests, were somewhat irregular in shape, which accounts to some extent for the apparent great loss in strength.

A majority of the samples show losses ranging from 326 to 2,000 lbs. per sq. in. A glance at the table shows that, in several instances, the frozen samples of sandstone gave an increase in strength, which, in one instance, reached 900 lbs. per sq. in. I attribute the fact that there is so little difference between the strength of fresh and frozen samples of sandstone to the capillary size of the pores, which allows the rapid dissipation of included water, by which they escape injury.

The higher crushing strength of the frozen samples over the fresh ones from the same quarry, as observed in a few cases, probably has no relation to the alternate freezing and thawing. It is probably due, as above mentioned, to a number of other causes, chief among which is the manner of preparing the cubes. If one set of samples are more carefully prepared than the other there is likely to be considerable variance in the results.

General Considerations.

Taking the results as a whole, we can safely conclude that freezing and thawing, if continued for a considerable period, will materially lessen the strength of the rock. Further, in spite of the exceptions above noted, we feel safe in concluding that, under ordinary circumstances, the loss in strength is greater in the case of granite and limestone than in the case of sandstone. The total loss in strength is, in a general way, proportional to the crushing strength of the rock. Building stone which has a high crushing strength, such as granite, shows a considerably greater relative loss than does sandstone. Likewise, the fresh samples of limestone, which have a very high crushing

strength, have a proportionately less crushing strength after being subjected to alternate freezing and thawing. In the case of both granite and limestone, the percentage of pore space is relatively small and the pores are of much smaller size than those occurring in the sandstone. The differences in crushing strength, as shown by these experiments, bear out the theory stated above, that a stone, in which the porosity is low and the size of the pores small, will, when saturated with water, suffer from alternate freezing and thawing much more than one in which the percentage of pore space is high and the size of the pores large. This is not shown by the loss in weight, being apparent only after a comparison of the crushing strength of the fresh and frozen samples.

There is no question but that of two stones, one with a high percentage and the other with a low percentage of pore space, if they are *completely* saturated with water when frozen, the former will suffer the greater injury. But one must consider the conditions under which the freezing takes place, if the results are to be of any practical value. In these conditions a time element enters, which modifies very essentially the results. After making this time element as short as the conditions under which the experiments were performed would permit, it was found that, apparently, the sandstone which had the highest percentage of pore space, had its strength proportionally less affected by freezing and thawing than the strong granites and limestones having low percentages of pore space. Naturally it was thought that the Dunnville sandstone, with its high percentage of pore space and relatively fine particles, would experience a greater loss in strength than any of the other rocks tested. It was therefore the occasion of no little surprise to find that this was not the case. This result gives additional evidence that even in as fine a grained rock as this, the pores must be of greater than subcapillary size, permitting the included water to be given off with sufficient rapidity to escape the evil effects of freezing.

It has been a matter of frequent observation that limestone and marble suffer more by hard freezing immediately after be-

ing taken from the quarry than other stones having a much greater porosity. The reason for this has never, to my knowledge, been adequately explained. It has usually been spoken of as exceptional, but I venture to say that between limestone or marble and sandstone the former can furnish more examples of injury by the freezing of the water contained in the pores than the latter. I do not refer here to the results of the freezing of water along the parting planes, which has been the cause of much of the scaling of sandstone, which has been laid, in walls, on edge. Prof. J. P. Merrill, in the 10th Census Report on Building Stones, gives a reason for the injury to freshly quarried limestone by freezing. He says: "It frequently happens that stones of very good quality are entirely ruined by hard freezing immediately after being taken from the quarry (this being particularly the case with some marbles and limestones), while if they are quarried during the warm season of the year and have an opportunity to lose their quarry water by evaporation prior to cold weather, they withstand freezing perfectly well. This phenomenon is easily accounted for if we admit the claim put forward by some that the quarry water of these stones carries in solution carbonate of lime and silica, which is deposited in the cavities of the rock as evaporation proceeds, thus furnishing additional cementing material and rendering the rock more compact." It is very probable that the water which evaporates from a limestone or marble leaves a deposit of mineral substance, which was held in solution by the interstitial water, but it is rather absurd to attribute this as the cause of the conditions above cited. The more reasonable explanation depends upon the *size of the pores,* which in limestone and marble are usually very small. The interstitial water is given off very slowly, and if the weather is very cold, it will freeze before evaporation can remove it. In this condition the pores are filled with water and the maximum injury results from freezing. After the limestone or marble has been thoroughly seasoned or dried it takes up water, only with great difficulty. If the stone is dry, it may be frozen a hundred times, and the injury will be scarcely no-

ticeable. If it is by some means saturated again, it will be subject to the same danger as when first taken from the quarry. The reason for injury from frost when first quarried, and apparent immunity from it after seasoned, in the above cited cases, is due to the small *size of the pores,* by which the stone is in danger when saturated, and out of danger when dry. The results are apparently not connected in any way with the deposit of calcium carbonate or silica.

THE EFFECT OF SULPHUROUS ACID GAS.

Limestone, dolomite, and marble are the only kinds of stone which are to any extent injured by sulphurous acid gas. Samples from the more important quarries were tested in the labortory of the Survey to determine the effect of this gas, as explained on page 74. After a treatment of 44 days in a moist atmosphere, the different samples showed little or no change in weight. (See Table VII.) Some of the pieces were colored yellow, others were slightly etched or corroded, while on the surface of many of the samples a glistening precipitate of magnesium salts had formed. The magnesium salts were easily dissolved in water, and in this manner the samples lost slightly in weight.

Dolomitic limestone, when placed in an atmosphere laden with moisture and sulphur dioxide, will gradually decrease in weight through the loss of magnesium salts. This process does not proceed very rapidly under ordinary conditions, but after a number of years' exposure in a large city where the consumption of bituminous coal is large, the limestone will show on the surface the effects of this gas.

THE EFFECT OF CARBONIC ACID GAS.

The results of the experiments performed to determine the effect of carbonic acid gas in a moist atmosphere, show no appreciable deterioration, either in weight or color. Table IX. gives the condition of the samples both before and after treatment.

It would be difficult to say just what would be the action of the carbon dioxide on limestone, when acting in conjunction

with sulphur dioxide. Neither can one tell the effect that the many other less abundant gases in the atmosphere would have upon the sample, when combined with either carbon dioxide, sulphur dioxide, or both.

THE EFFECTS OF HIGH TEMPERATURE.

Few experiments have thus far been performed to determine the limit of temperature which the different kinds of building stone will stand without injury. It has been demonstrated that a stone will stand a much higher temperature when heated and cooled slowly, than when heated or cooled rapidly. The rapid changes in temperature occasioned by throwing cold water on a rock have a tendency to destroy it much more quickly, when it is highly heated, than a gradual increase or decrease of heat. A stone which has been heated to a high temperature may apparently be unaffected at the maximum heat, but when cooled again it may be found that the strength is almost entirely gone. High temperature results in loosening the grains of a stone by cracking the individuals and injuring the cement.

As a result of the experiments which are recorded in Table X., it was discovered that all the samples, when struck by the hammer or scratched with a nail, after being taken from the muffle furnace, emitted a sound very similar to that which would be given off by a brick. This sound was characteristic not only of the sandstones, but also of the granites and some of the limestones.

The planes of lamination of the originally stratified samples were brought out more distinctly as the temperature was increased. But few of the limestone samples, which were tested in the muffle furnace, were injured by gradual heating and cooling, except when the temperature reached a point where calcination occurred. This temperature was generally from 1000°–1200° F. When the limestone samples were suddenly cooled, they always flaked at the corners, as shown in Plate LVII. The uncalcined cores to the samples were somewhat rounded at the corners and in some instances broke into small fragments after a week or two of exposure to the atmosphere.

The manner in which the granite samples were affected is illustrated in Plate LVI. It will be observed that the different samples when rapidly cooled cracked very differently. The very coarse grained granite broke into a great many pieces, and may be said to have exploded. The cracks were so numerous that the stone was broken into fragments not much larger than the individual grains. The medium grained granite, such as occurs at Granite Heights, flaked off at the corners, as shown in Plate LVII. The fine grained, compact granite, such as the Montello, developed cracks through the middle of the sample. These cracks were fine and quite regular, as shown in Plate LVI.

In contrast with the limestone and granite samples, the sandstones were, to all outward appearances, little injured by the extreme heat. The samples which were taken from the muffle furnace and allowed to cool gradually were apparently as perfect as when first placed in the furnace. But after they had cooled, one could crumble any of them in the hand, almost as readily as the softest incoherent sandstone. In fact when they were heated to a temperature of 1500° F. some of the samples had become so incoherent that it was barely possible to pick them up after cooling, without their falling to pieces. One or two exceptions to this rule were noted in the finer grained varieties of sandstone from the Lake Superior brownstone region. One of these samples showed apparently little deterioration in strength, as has been previously noted in the description of the individual quarries.

One might very easily be deceived regarding the amount of injury occasioned by extreme heat on the coarser grained sandstone. After heating, the samples, as a rule, look as fresh and clean as when first quarried, and unless tested with a hammer, one would never suspect that the strength was so largely gone. The samples emit the characteristic ring and scratch of brick, which is in the sandstone more closely analogous to brick than in either limestone or granite.

In general, the results of the temperature tests seem to indicate that there are but few, if any stones, whether they be gran-

ite, limestone, or sandstone, that will effectively withstand the extreme temperature of 1500° F. The samples which were tested in the laboratory of the Survey were allowed to remain only 5 or 10 minutes in the furnace at this extreme temperature before being removed. It is thought that if they had been permitted to remain one-half or three-quarters of an hour there are none that would not have been destroyed by the intense heat. There is probably no stone that will not suffer ultimate destruction if extreme heat be applied for a considerable time.

But it must be understood that the Wisconsin building stone is no different in this respect from the stone obtained from other states. Neither the Bedford nor Joliet limestone will stand higher temperatures without injury than the limestone from Wisconsin. No sandstone, whether it be quarried in Michigan or Connecticut, will resist heat more effectually than the Lake Superior brown sandstone of Wisconsin. A stone is seldom subjected to a heat which approaches the maximum recorded in these tests, except in large conflagrations. It is seen by reference to Table X., that up to a temperature of 800° F., the stone tested was little, if any, injured. The brown sandstone does not suffer through rapid changes of temperature in the way the limestone and granite do. It seldom flakes or cracks, and is only destroyed at a temperature that no stone is capable of withstanding. It appears, not alone from experiment, but from actual use in buildings, to be especially well adapted to withstand moderately high temperatures. In a number of instances buildings built out of brownstone have been entirely destroyed, with the exception of the walls, which have remained, almost without a block destroyed. This can scarcely be said of other building stone or brick.

It would be interesting to know just what the loss in strength is for each increment of 100–200° for different building stones. This could only be determined by a careful series of experiments, which would take more time than has been at my disposal. It is to be hoped, that in the future, some experiments may be performed which will give results by which some ratio may be made out between the effect of heat and the loss in strength.

What actually takes place in a stone when heated is not definitely known, yet it is quite certain that the contraction and expansion of the individual particles, as they are heated and cooled, differ to such an extent that rupture takes place throughout the entire mass of the sample tested. These innumerable ruptures which occur between the particles composing the rock occasion the loss in strength, which makes the rock unfit for future use.

RÉSUMÉ.

In the accompanying tables an attempt has been made to give as completely as possible the characteristics of the stone from the different quarries in Wisconsin. The tables are necessarily somewhat incomplete, but are meant to cover as fully as practicable the more important tests of building stone. We have noted in some instances that the stone from Wisconsin is exceptionally strong, that the limestone, granite, and rhyolite have a crushing strength which is unsurpassed by any other stone in the United States. The porosity and specific gravity are such that the Wisconsin building stone must be placed among those which are best adapted to withstand the rigors of a temperate climate. The actual tests of freezing and thawing reveal the fact that there is little loss in weight, but some differences in strength between the fresh and frozen samples, and that the relative loss in strength is greater as the samples are more compact and the pores smaller. It has further been pointed out that carbonic acid gas has but little effect upon the durability of limestone, while sulphurous acid gas discolors the rock, and brings magnesium salts out upon the surface. The test also shows that granite, sandstone, and limestone, alike, are incapable of withstanding exterme heat, but that up to a moderate temperature of 800° or 1000° F., few of the building stones tested were materially injured. The tests as a whole show that the first grades of all classes of Wisconsin stone, granite, rhyolite, limestone, and sandstone, meet all the demands as to strength and durability which are required of stone for building purposes.

TABLE I.

Calibration of Riehle Automatic Testing Machine. Capacity of 100,000 lbs.

Increment.	Total load.	Beam.	Error.	Increment.	Total load.	Beam.	Error.
5,150	5,150	5,128	22 +	5,737	46,612	46,468	144 +
4,832	9,982	10,158	176—	4,918	51,530	51,468	62 +
5,772	15,756	15,978	222—	4,788	56,318	56,263	155 +
5,737	21,493	21,568	75—	4,807	61,125	60,968	157 +
4,833	25,326	25,333	7—	4,829	65,954	65,878	76 +
5,858	31,184	31,303	119—	5,843	71,797	71,578	219 +
4,971	36,055	36,083	28—	4,827	76,624	76,558	266 +
4,820	40,875	40,828	47 +	3,730	80,354	80,075	281 +

TABLE II.

Crushing Strength.

Name of Quarry.	Location.	Average area of bearing faces.	First crack.	Ultimate strength of sample.	Ultimate strength in pounds per square inch.	Remarks.
GRANITE AND RHYOLITE.						
Amberg Gran. Co.....	Athelstane.......	3.978	50,500	60,320	15,163	Exploded. Some traces of a pyramid.
Amberg Gran. Co.....	Athelstane.......	3.944	....	92,080	23,347	Good pyramids. Remainder of each sample was reduced to sand and small fragments.
Amberg Gran. Co.....	Athelstane.......	4.000	78,630	80,580	20,145	
Amberg Gran. Co.....	Athelstane.......	4.187	81,850	89,180	21,299	
Berlin Gran. Co.......	9 miles from Berlin..............	3.952	82,790	96,000	24,800	Broke with explosion.
E. J. Nelson Gran. Co.	Berlin.					
On head............	....	4.184	186,000	199,470	47,674	Good small pyramid.
On bed............	....	4.307	146,000	190,550	44,009	Good small pyramid.
French Gran. Co......	High Bridge.....	4.185	....	97,765	24,229	Broke with explosion.
Granite Heights Co...	Granite Heights.	3.950	80,085	87,135	22,060	
Granite Heights Co...	Granite Heights.	3.934	88,260	90,310	22,954	
Jenk's Quarry	Irma	4.188	78,055	78,200	18,677	Very fair pyramids.
Jenk's Quarry	Irma	4.187	26,410	53,190	12,704	Specimen broke on side.
Jenk's Quarry	Irma	4.338	85,800	98,430	22,690	Exploded. Fair pyramid.
Leuthold's Quarry ...	Granite City.....	4.097	94,670	100,000	25,000	Not crushed.
L. S. Cohn Gran. Co..	Granite Heights.	3.593	30,000	53,930	15,009	Broke on side.
L. S. Cohn Gran. Co..	Granite Heights.	3.730	90,000	98,920	26,520	
L. S. Cohn Gran. Co..	Granite Heights.	4.016	49,300	66,960	16,723	Exploded. Upper pyramid good.
L. S. Cohn Gran. Co..	Granite Heights.	4.075	76,180	99,770	24,483	
Milw. Monument Co..	Waushara Co., 11 miles from Berlin.............	4.151	155,000	158,000	38,063	After removing from a 100,000 to a 200,000 lb. machine.
Milw. Monument Co..	Waushara Co.. 11 miles from Berlin.............	4.249	91,000	146,725	34,531	Fair pyramids.
Milw. Monument Co..	Waushara Co., 11 miles from Berlin.............	4.190	77,000	131,260	31,326	
Montello Gran. Co....	Montello.........	4.301	182,500	189,140	43,973	
Montello Gran. Co....	Montello.........	4.301	182,000	187,700	43,639	
Montello Gran. Co....	Montello.........	4.290	88,000	116,400	27,132	Broke on corner. Very poor faces.
New Hill O'Fair......	Granite Heights.	4.058	109,000	110,640	27,262	After having been under 100,000 lbs. pressure and removed to a 200,000 lb. machine.
Pike Riv. Gran. Co... (Gray granite.)	Amberg	4.069	94,000	113,475	27,887	Removed from the 100,000 to the 200,000 lb. machine.
Pike Riv. Gran. Co... (Red granite.)	Amberg	4.277	51,910	78,000	18,237	Pyramids at top and bottom. Much shattered.

TABLE II — Continued.

Crushing Strength.

Name of Quarry.	Location.	Average area of bearing faces.	First crack.	Ultimate strength of sample.	Ultimate strength in pounds per square inch.	Remarks.
GRANITE AND RYOLITE — continued. *Tested by other parties.*						
E. J. Nelson Gran. Co.	Berlin............	3.190	....	100,000	31,300	Tested by Fuldner and McDonald in laboratory of University of Wisconsin.
E. J. Nelson Gran. Co.	Berlin............	1.410	....	46,153	32,747	
E. J. Nelson Gran. Co.	Berlin............	2.500	....	64,200	25,680	
Montello Gran. Co....	Montello.........	3.370	....	100,000	29,625	Not crushed.

TABLE II.—Continued.
Crushing Strength.

Name of Quarry.	Location.	Position in testing machine.	Average area of bearing faces.	First crack.	Ultimate strength of sample.	Ultimate strength in pounds per square inch.	Remarks.
LIMESTONE.							
Bauer's Quarry	Knowles	Bed	4.117	120,175	120,175	29,189	
Bauer's Quarry	Knowles	Edge	4.145	102,000	133,350	32,171	
Bridgeport Stone Quarry	Bridgeport	Bed	3.565	36,050	36,050	10,112	
Bridgeport Stone Quarry	Bridgeport	Edge	3.656	27,450	27,450	7,508	
Bridgeport Stone Quarry	Bridgeport	Bed	1.159	....	7,740	6,675	
Gillen Stone Co	Duck Creek	Edge	4.083	67,840	100,000	25,000	Corners broken or chipped. Not ultimate strength.
Gillen Stone Co	Duck Creek	Bed	4.083	80,500	97,225	23,783	Fair pyramids.
Gillen Stone Co	Duck Creek	Bed	4.035	98,100	100,000	24,783	Stone cracked on two corners. Not crushed.
Laurie Stone Co	Sturgeon Bay	Bed	3.708	71,000	115,500	31,957	First crack on the corner.
Laurie Stone Co	Sturgeon Bay	Edge	3.776	134,000	151,000	39,983	
Lee Brothers	Genesee	Bed	4.176	151,000	153,400	36,731	Very good pyramids.
Lee Brothers	Genesee	Edge	4.167	120,000	122,500	29,253	
Marblehead Lime and Stone Co	Marblehead	Bed	3.721	143,000	159,210	42,787	Very good upper pyramid.
Marblehead Lime and Stone Co	Marblehead	Edge	3.674	148,625	148,625	40,453	
Menominee Falls Quarry Co	Lannon	Bed	4.235	132,000	135,250	31,936	Very good pyramids.
Menomonee Falls Quarry Co	Lannon	Edge	4.330	145,000	145,000	33,485	
Oenning & Giesen Quarry	Fountain City	Bed	3.728	22,685	32,920	8,830	Broke quietly. Very fair pyramid.
Oenning & Giesen Quarry	Fountain City	Edge	3.828	33,390	33,525	8,768	Fair pyramid.
Story Brothers' Qu'rry	Wauwatosa	Bed	4.500	86,000	86,000	19,111	Hammer dressed samples. Rough except on bearing faces.
Story Brothers' Qu'rry	Wauwatosa	Bed	5.100	....	90,000	17,647	
Story Brothers' Qu'rry	Wauwatosa	Edge	4.550	....	61,000	13,406	
Story Brothers' Qu'rry	Wauwatosa	Edge	4.300	....	102,100	23,744	
Voree Quarry	Burlington	Bed	3.895	43,340	47,000	12,066	
Voree Quarry	Burlington	Edge	3.522	43,100	48,880	13,588	
Washington Stone Co.	Sturgeon Bay	Bed	1.110	....	35,300	31,800	
Washington Stone Co.	Sturgeon Bay	Bed	1.170	....	36,350	31,065	

TABLE II.— Continued.

Crushing Strength.

Name of Quarry.	Location.	Position in testing machine.	Average area of bearing faces.	First crack.	Ultimate strength of sample.	Ultimate strength in pounds per square inch.	Remarks.
			LIMESTONE—continued.				
Washington Stone Co.	Sturgeon Bay	Bed ..	1.070	22,300	33,000	30,841	
Washington Stone Co.	Sturgeon Bay	Bed ..	3.590	....	106,000	29,526	Did not break. Maximum strength not reached.
Washington Stone Co.	Sturgeon Bay	Edge .	3.844	99,660	100,000	26,014	Not ultimate str'gth. Shattered on one corner. Has a scaly fracture.
Washington Stone Co.	Sturgeon Bay	Bed ..	3.879	106,250	118,080	30,435	
Washington Stone Co.	Sturgeon Bay	Edge .	3.974	141,000	141,150	35,518	
			Tested by other parties.				
Waukesha Stone Co..	Waukesha ...	Bed ..	3.500	....	67,320	19,234	Tested by Fuldner and McDonald in laboratory of University of Wisconsin. Second sample was not crushed.
Waukesha Stone Co..	Waukesha ...	Bed ..	7.900	....	100,000	....	
			SANDSTONE.				
Ashland Brownst. Co.	Presque Isle.	Bed ..	4.052	....	25,300	6,244	
Ashland Brownst. Co.	Presque Isle.	Edge .	4.205	....	19,960	4,747	
Ashland Brownst. Co.	Presque Isle.	Edge .	4.072	....	8,150	2,001	Fair pyramids.
Argyle Brownstone Co	Argyle........	Bed ..	4.219	21,060	21,060	5,000	Very fair pyramid.
Argyle Brownstone Co	Argyle........	Bed ..	3.576	13,170	14,000	3,915	
Argyle Brownstone Co	Argyle........	Edge .	3.900	5,415	6,875	1,763	Not very good pyramids. Broke on one side.
Argyle Brownstone Co	Argyle........	Edge .	3.945	13,130	13,200	3,346	Good pyramids.
Argyle Brownstone Co	Argyle........	Bed...	3.705	12,640	12,640	3,411	Two very fair pyramids.
Babcock & Smith.....	Houghton....	Bed ..	4.308	27,895	27,980	6,502	Good pyramids.
Babcock & Smith.....	Houghton....	Edge .	4.219	16,785	17,580	4,166	
Babcock & Smith	Houghton....	Bed ..	4.341	....	18,840	4,340	Good pyramids.
Bass Island Brownst.	Bass Island..	Bed ..	5.180	26,450	26,550	5,126	
Bass Island Brownst.	Bass Island..	Edge .	5.167	....	22,270	4,310	
C. & N. W. Ry. Co	Ablemans	Bed* .	4.064	30,620	38,280	9,419	Fair pyramids.
C. & N. W. Ry. Co	Ablemans	Bed* .	3.998	44,940	54,650	13,669	Good pyramids.

* White.

TABLE II.—Continued.

Crushing Strength.

Name of quarry.	Location.	Position in testing machine.	Average area of bearing faces.	First crack.	Ultimate strength of sample.	Ultimate strength in pounds per square inch.	Remarks.
SANDSTONE — continued.							
C. & N. W. Ry. Co	Ablemans	Edge*	3.988	30,000	49,250	12,350	Good pyramids.
C. & N. W. Ry. Co	Ablemans	Edge*	4.032	41,600	46,560	11,547	Good wedge.
C. & N. W. Ry. Co	Ablemans	Bed†..	4.010	15,615	32,410	8,082	Two imperfect pyramids.
C. & N. W. Ry. Co	Ablemans	Bed† .	4.155	42,705	52,450	12,623	
C. & N. W. Ry. Co	Ablemans	Edge†	4.044	17,500	30,100	7,443	Poor pyramids.
C. & N. W. Ry. Co....	Ablemans	Bed† .	4.048	38,100	47,650	11,030	Fair pyramids.
C. & N. W. Ry. Co	Ablemans	Edge‡	4.243	19,525	28,650	6,680	Fair pyramids.
C. & N. W. Ry. Co	Ablemans	Bed‡ .	4.014	30,490	53,915	13,431	Fair pyramids.
C. & N. W. Ry. Co	Ablemans	Edge‡	3.992	30,500	50,165	12,566	Fair pyramids.
C. & N. W. Ry. Co....	Ablemans ...	Bed* .	4.014	31,455	40,365	10,056	Wedge.
C. & N. W. Ry. Co	Ablemans	Bed§ .	4.070	20,100	35,010	8,602	Fair pyramid.
C. & N. W. Ry. Co....	Ablemans	Edge .	4.068	10,000	14,250	3,502	Poor pyramids.
Duluth Brownst. Co..	Across River from Fond du Lac, Minn.	Bed ..	4.060	18,585	24,080	5,931	Some trace of pyramids.
Duluth Brownst. Co..	Across River from Fond du Lac, Minn.	Edge .	4.010	24,730	26,710	6,052	Fair pyramids.
Duluth Brownst. Co.	Across River from Fond du Lac, Minn.	Bed ..	4.113	16,910	19,200	4,668	Fair pyramids.
Dunnville.............	Dunnville....	Bed ..	4.128	....	10,330	2,502	Pyramids.
Dunnville.............	Dunnville....	Edge .	3.812	....	11,215	2,942	Pyramids.
Dunnville.............	Dunnville....	Bed ..	4.039	7,120	10,285	2,544	Broke on one side. Poor pyramids.
Grover Red Sandstone	La Valle. ...	Bed ..	4.068	....	54,300	13,350	Broke with explosion. Two fair pyramids.
Grover Red Sandstone	La Valle.....	Edge .	4.186	....	47,090	11,460	
Pike's Quarry.........	Bayfield......	Bed ..	4.297	....	19,715	4,588	Fair pyramids.
Pike's Quarry.........	Bayfield......	Edge .	4.105	....	14,335	3,492	Fair pyramids.
Port Wing Brownst..	Port Wing...	Bed ..	4.038	....	22,200	5,498	Good pyramids.
Port Wing Brownst..	Port Wing...	Edge .	4.058	....	6,730	1,658	Good pyramid on bottom, poor on top.
Port Wing Brownst..	Port Wing...	....	4.142	....	21,380	5,161	
Port Wing Brownst..	Port Wing...	....	3.937	... .	18,065	4,588	
Port Wing Brownst...	Port Wing...	....	4.071	....	20,815	5,113	
Port Wing Brownst...	Port Wing...	....	4.208	....	21,735	5,165	
Prentice Brownst. Co.	Houghton....	Bed...	4.573	20,800	20,800	4,549	
Prentice Brownst. Co.	Houghton....	Edge .	3.984	15,385	16,290	4,090	

*White. †Light brown. ‡Dark brown. §Brown.

TABLE II.—Continued.

Crushing Strength.

Name of Quarry.	Location.	Position in testing machine.	Average area of bearing faces.	First crack.	Ultimate strength of sample.	Ultimate strength in pounds per square inch.	Remarks.
			SANDSTONE — continued.				
			Tests by other parties.				
Bass Island...........	....	....	......	....	....	4,662	Tests made by Gen. Gilmore.
Fond du Lac	....	....	......	....	....	6,237	Tests made by Gen. Gilmore.
Houghton.............	....	....	......	....	....	7,816	Tests made by Columbia School of Mines.
Port Wing Brownst...	Port Wing...	....	4.300	....	35,100	8,162.8	Tests made by Harry F. Smith, University of Mindesota.
Port Wing Brownst...	Port Wing...	....	4 330	....	44,100	10,184.7	
Wilson Island.........	....	....	......	....	....	7,548	

TABLE III.

Transverse Strength.

Name of Quarry.	Length in inches.	Breadth in inches.	Height in inches.	Weight of load in pounds.	Modulus of rupture in lbs. per sq. in.	Remarks.
GRANITE.						
Montello Gran. Co....	4	1.007	1.100	794	3,909.7	
Montello Gran. Co....	4	0.982	1.066	684	3,677.9	Broke ¼ in. from center.
New Hill O'Fair.......	4	1.017	0.995	426	2,324.3	Broke diagonally across center.
New Hill O'Fair.......	4	1.067	1.103	598	2,713.1	The granite samples break suddenly. Very little bending.
LIMESTONE.						
Bauer's Quarry.......	7	1.073	1.035	284	1,609.1	Broke 1 in. from center.
Bridgeport Quarry ...	6	1.060	1.067	157	1,164.3	Broke ¼ in from center.
Laurie Stone Co......	5	1.049	1.020	678	4,659.2	Broke very close to center.
Lee Bros.' Quarry....	6	1.098	1.120	368	2,404.5	Broke ½ in. from center.
Marblehead L. & S.Co.	6	1.076	1.074	501	3,632.8	Broke exactly in center.
Menominee Falls Co..	6	1.090	1.032	409	3,170.6	Broke very close to center.
Story Bros	6	0.927	1.080	245	2,042.0	
Story Bros	6	0.967	1.094	285	2,217.0	
Washington Stone Co.	6	1.078	1.030	345	2,715.1	Imperfect samples. Broke where flaw was noticed.
Washington Stone Co.	5	1.079	1.025	593	3,923.3	Broke at center.
SANDSTONE.						
Babcock & Smith.....	3.5	1.012	1.200	145	522.4	
Babcock & Smith.....	3.5	0.997	1.045	110	530.4	
Bass I. Brownst'ne Co.	3.5	0.953	1.045	110	655.0	
Bass I. Brownst'ne Co.	3.5	0.972	1.044	108	534.9	
C. & N. W. Ry. Co.....	4.0	1.022	1.032	240	1,324.0	
C. & N. W. Ry. Co.....	4.0	1.023	1.027	152	845.0	
C. & N. W. Ry. Co.....	4.0	1.023	1.046	185	992.0	
C. & N. W. Ry. Co.....	4.0	1.007	1.023	180	1,025.0	
C. & N. W. Ry. Co.....	4.0	1.018	1.047	170	914.0	
C. & N. W. Ry. Co.....	4.0	1.007	1.018	170	985.0	
Flag River B. Stone...	7.0	1.140	1.096	65	498.8	Broke ½ in. from center.
Flag River B. Stone...	7.0	1.047	1.110	48	391.0	Broke about ½ in. from center.

Table III.—Continued.

Transverse Strength.

Name of Quarry.	Length in inches.	Breadth in inches.	Height in inches.	Weight of load in pounds.	Modulus of rupture in lbs. per sq. in.	Remarks.
			SANDSTONE.—continued.			
Grover Red S.Stone...	3.0	0.965	0.964	30	150.2	Sample was wet.
Grover Red S.Stone...	3.0	1.063	0.955	79	362.9	
Prentice Br'nstone Co.	5	1.050	1.115	100	574.6	
Prentice Br'nstone Co.	5	1.095	1.100	82	464.2	The sandstone breaks slowly. The sample first bends, then cracks, and finally breaks across, quietly.

Table No. IV.

Modulus or Coefficient of Elasticity.

Name of Quarry.	Location.	Position in testing machine.	Modulus of elasticity in pounds per sq. in.	Remarks.
GRANITE AND RHYOLITE.				
Amberg Granite Co...	Athelstane	....	201,900	
Amberg Granite Co...	Athelstane	....	979,700	
Amberg Granite Co...	Athelstane	....	951,500	
Amberg Granite Co...	Athelstane	....	1,175,500	
Berlin Granite Co....	Near Berlin......	....	505,700	
French Granite Co....	High Bridge.....	....	771,700	
Granite Heights Co..	Granite Heights.	....	1,450,000	
Jenk's Quarry........	Irma	....	582,000	
Jenk's Quarry........	Irma	....	156,000	
L. S. Cohn Granite Co	Granite Heights.	....	1,040,000	
L. S. Cohn Granite Co	Granite Heights.	....	1,080,400	
Milw'k'e Monum't Co	Near Berlin......	....	688,400	
New Hill O'Fair......	Granite Heights.	....	1,815,000	
Pike River Gran. Co. (Gray).............	Amberg	....	1,465,900	
(Red)	Amberg	....	853,000	
E. J. Nelson Gran. Co.	Berlin...........	....	1,004,200	Results obtain'd from tests made by Fuldner and McDonald in the laboratory of the University of Wisconsin.
E. J. Nelson Gran. Co.	Berlin...........	....	1,916,200	
Montello Granite Co.	Montello	....	1,614,400	
Montello Granite Co.	Montello	....	1,735,300	
Montello Granite Co.	Montello	....	2,070,000	
Montello Granite Co.	Montello	....	1,658,000	
LIMESTONE.				
Gillen Stone Co.......	Duck Creek......	Bed	462,800	
Oenning & Giesen....	Fountain City...	Bed	171,000	
Oenning & Giesen....	Fountain City...	Edge	287,900	
Voree Stone Quarry..	Burlington.......	Bed	31,500	
Voree Stone Quarry..	Burlington.......	Edge	501,300	
Washington Stone Co	Sturgeon Bay....	Bed	674,500	
Washington Stone Co	Sturgeon Bay....	Edge	869,400	
Waukesha Stone Co..	Waukesha	....	1,327,500	Results obtained by Fuldner and McDonald as above.
Waukesha Stone Co..	Waukesha	....	1,225,000	

Table No. IV.—Continued.

Modulus or Coefficient of Elasticity,

Name of Quarry.	Location.	Position in testing machine.	Modulus of elasticity in pounds per sq. in.	Remarks.
LIMESTONE — continued.				
Waukesha Stone Co..	Waukesha	....	1,835,700	Results obtained by Fuldner & McDonald.
Waukesha Stone Co..	Waukesha	....	1,312,300	
SANDSTONE.				
Ashland Brownst. Co	Presque Isle	Bed	114,500	
Ashland Brownst. Co	Presque Isle.....	Edge	94,000	
Argyle Brownstone Co	Argyle..	Edge	65,500	
Argyle Brownstone Co	Argyle............	Bed	96,000	
Argyle Brownstone Co	Argyle............	Bed	116,000	
Argyle Brownstone Co	Argyle............	....	41,300	
Babcock & Smith.....	Houghton........	Bed	387,900	
Babcock & Smith.....	Houghton........	Bed	120,400	
Babcock & Smith.....	Houghton........	Edge	224,000	
Bass Isl. Brownst. Co	Bass Island......	Bed	76,300	
Bass Isl. Brownst. Co	Bass Island......	Edge	64,900	
C. & N. W. Ry. Co....	Ablemans	Bed	205,700	
C. & N. W. Ry. Co....	Ablemans	Bed	236,900	
C. & N. W. Ry. Co....	Ablemans	....	135,100	
C. & N. W. Ry. Co....	Ablemans	....	400,800	
C. & N. W. Ry. Co....	Ablemans	....	224,900	
C. & N. W. Ry. Co....	Ablemans	....	209,000	
Duluth Brownst'ne Co	Near Fond du Lac, Minn	Bed	80,600	
Duluth Brownst'ne Co	Near Fond du Lac, Minn	Edge	90,900	
Dunnville Quarry....	Dunnville........	Edge	32,000	
Dunnville Quarry....	Dunnville........	Bed	103,420	
Dunnville Quarry....	Dunnville........	Edge	145,800	
Grover Red Sandsto'e	LaValle..........	Bed	316,300	
Grover Red Sandsto'e	LaValle..........	Edge	376,100	
Pike's Quarry.........	Bayfield..........	Bed	212,600	
Pike's Quarry	Bayfield.....	Edge	140,000	
Prentice Brownst. Co	Houghton........	Bed	170,600	
Prentice Brownst. Co	Houghton........	Edge	151,800	

TABLE V.

Specific Gravity, Porosity, Ratio of Absorption, and Weight per Cubic Foot.

Weights are in grams and fractions thereof on Jos. Nemetz-Wein balances.

Name of quarry.	Approximate average area of the faces of the cubic samples in square inches.	First dry weight.	Weight of sample after soaking 36 hours.	Weight of sample after soaking 72 hours.	Weight of sample suspended in water.	Second dry weight.	Average of first and second dry weights.	Specific gravity.	Weight of water absorbed.	Percentage of pore space or porosity.	Percentage of the weight of absorbed water to the av. dry weight of the sample, or ratio of absorption.	Weight of the dry stone in pounds p'r cubic foot.
					GRANITE.							
Amberg Granite Co.	4 012 3 968	355.69 349.57	355.77 349.92	355,73 349.98	224.53 220.10	355.57 349.53	355.585 349.55	2.713 2.70	.143 .430	.108 .331	.040 .123	169.05 167.95
Berlin Granite Co	3.734 3.952	300.72 338.82	301.15 339.26	301.11 339.25	186.91 210.56	300.64 337.68	300.680 338.745	2.643 2.642	.430 .508	.378 .392	.143 .149	164 20 164.15
E. J. Nelson Granite Co	4.310 4.208	378.53 379.11	378.71 379.43	378.75 379.43	235.96 236.03	378.54 379.02	378.535 379.065	2.640 2.643	.245 .365	.170 .248	.064 .096	164.42 164.39
French Granite Co.	4.140	369.61	370.22	370.30	231.24	369.44	369.525	2.672	.775	.55	.209	165.79
Granite Heights Granite Co.	3 962 3.857	340.25 327.30	340.80 327.72	340.83 327.76	210.92 202.88	340.16 327.31	340.205 327.305	2 631 2.630	.625 .455	.48 .36	18 .14	163.43 163.61
Green Lake Granite Co	about 4.000	462.42	462.56	....	287.64	... .	462.41	2.645	.15	.019	.086	161.90
J. H. Leuthold	4 087 4.326	372.12 364.74	372.43 365.11	372.43 365.12	232 90 228.35	371.75 364.44	371.935 364.590	2 675 2.677	.495 .530	.354 .388	.133 .145	166.31 166.35
Milwaukee Monument Co.	4.186 4.129	373.66 370.19	374.32 370.31	374.30 370.84	232.08 229.98	373.65 370.05	373.65 370.12	2.639 2.641	.74 .79	.519 .56	.20 .21	163 77 163 90

Montello Granite Co.	4.194 4 263	372.91 378.92	373.16 379.30	373.20 379.30	231 63 235.38	372.90 378.93	372.905 378.925	2.639 2.641	.295 .375	.208 .266	.079 .099	164.28 164.38
New Hill O'Fair	3.931	343.32	343.72	343.74	212.70	343.17	343.245	2.629	.495	.377	.144	163.49
O. J. Jenks	4.323 4.088	370.57 368.14	371.36 368.70	371.40 368.76	230.58 229.10	370.47 368.12	370.52 368.13	2.646 2.647	.88 .63	.62 .45	.23 .17	164.10 164 46
Pike River Granite Co. (gray)	4 009 3.828	346.00 304.35	346.85 304.60	346.86 304.56	217.47 190.95	346.45 304.22	346.525 304.285	2 655 2.654	.335 275	.255 .241	.097 .090	167 09 167 13
Pike River Granite Co (red)	4.277 4 289	367.45 371.75	367.84 372.12	367.84 372.10	229.23 231.80	367.40 371.65	367.425 371.725	2 659 2.656	415 .375	.329 .267	.113 .100	165.46 165 36
The L. S. Cohn Granite Co.	3.593 3.87	304.11 306.77	304.55 307.30	....	188.45 190.09	....	304.01 306 71	2.629 2.630	.54 .59	.17 .19	.43 .50	163.40 163.29
					LIMESTONE.							
Bridgeport	about 2 25	131.23 135.05	138.25 142 43	138.37 142.63	83.83 85.90	131.17 135.05	131.20 135.05	2.740 2 747	7.17 7.58	13 02 13.36	5.46 5.60	148 74 148 50
F. S. Bauer's	about 2.25	174.14 176.07	177.35 179.40	177.25 179.32	111.79 113.27	174.13 176.05	174.135 176.600	2.793 2.788	3.115 2.720	4.75 4.11	1.79 1 54	166 02 166.85
Gillen Stone Co.	4.111 4.092	377.55 393.03	379.05 394.32	379.05 394.36	244.75 254.45	377.40 393.12	377.475 393.075	2 843 2.836	1.575 1 255	1 17 0.91	0 419 0.32	175.34 175.40
Laurie Stone Co	about 2.25	189.45 179.79	189.85 180.21	189.81 180.21	122.77 116.44	189.45 179.77	189.45 179.78	2.841 2.700	.36 .43	.53 .64	.19 .24	176.26 168.27
Lee Brothers	about 2 25	152.57 159.66	154.25 161.46	154.22 161.46	98.70 103.22	152.52 159.62	152.545 159.635	2 833 2.829	1.675 1.825	3.01 3.12	1 10 1.15	171 43 171 00
Marblehead Lime & Stone Co.	about 2.25	166.79 172.85	167.32 173 28	167.30 173.26	108.40 112.20	166.79 172.85	166.79 172.85	2.856 2.849	.51 .41	.86 .67	.31 .24	176 69 176.51
Menominee Falls Stone Co	about 2.25	181.02 177.79	183 51 180.35	183.40 180.25	116.70 114.65	180.99 177.78	181.005 177.785	2.814 2.815	2 395 2.465	3 58 3.75	1.32 1.39	169 32 169 02
Oenning & Giesen	about 2.25	140.29 134.10	147.10 140.30	147.21 140 35	90.25 86.35	140.25 134.08	140.27 134.09	2.804 2.808	6.94 6 26	12.18 11.14	4 95 5 00	153.69 155 68
Story Brothers	about 1 00	42.40 45.11	43.37 46.15	43.37 46.15	27.37 29.15	42.40 45.11	42.40 45.11	2 821 2.826	.97 1.14	6.14 6.66	2.29 2.53	166 20 164.56

TABLE V.— continued.

Specific Gravity, Porosity, Ratio of Absorption, and Weight per Cubic Foot.

Weights are in grams and fractions thereof on Jos. Nemetz-Wein balances.

Name of quarry.	Approximate average area of the faces of the cubic samples in square inches.	First dry weight.	Weight of sample after soaking 36 hours.	Weight of sample after soaking 72 hours.	Weight of sample suspended in water.	Second dry weight.	Average of first and second dry weights.	Specific gravity.	Weight of water absorbed.	Percentage of pore space or porosity.	Percentage of the weight of absorbed water to the av. dry weight of the sample, or ratio of absorption.	Weight of the dry stone in pounds p'r cubic ft.
LIMESTONE.— continued.												
Voree Stone Quarry.........	about 4 00	346.63 336.72	358.05 347.40	358 14 347 53	222.08 213.56	346 86 336 50	346.755 336.610	2.781 2.780	11.386 10.940	8 36 8.28	3 28 3.25	159.01 159.14
Washington Stone Co.........	about 2.25	197.28 194.35	197.78 194.76	197.72 194.73	127.41 125.39	197 20 194.34	197.240 194.345	2 824 2.818	.48 .385	.63 .55	.24 .20	175.02 174.83
SANDSTONE.												
Argyle Brownstone Co.......	3.724 3.790	246.50 243.23	269 61 266.00	267.22 266.09	153.72 151 73	246.08 243.15	246.29 243.19	2 660 2.658	20.93 22.90	18.12 20.01	8 49 9.20	135.93 132.74
Ashland Brownstone Co... ..	3.976 4.008	265.79 272.27	288 55 298.95	288.79 297.26	163.00 168.75	265.80 272.20	265.795 272.235	2.637 2.630	22.995 25.025	18.57 19.46	8.65 9.19	133.99 132.18
Bass Island Br'wns'tne Co...	5.205 5.302	366.85 412.10	402.5 453.4	402.42 453.70	227.68 255.95	366.85 412.00	366.85 412.05	2.635 2.639	35 57 41 65	20.34 21.05	9.69 10.11	130.96 129 97
C. A. Bender..............	3 887 4 120	273 41 302 22	290 62 321.60	291.15 322.21	169.13 187 18	273.30 302.15	273.355 302.185	2 623 2 627	17.795 20 025	14.84 14.82	6 51 6.63	139.41 139 65
C. & N. W. Ry. Co..........		326.93 312.06	332 96 322.36	333.47 323.18	197.43 187.20	326.91 312.05	326.92 312.05	2.524 2.490	6.55 11.125	4 81 8.18	2 00 3.57	149.92 143.24

C. & N. W. Ry. Co.	3.988	311.53	318.50	....	192.00	311.45	311.49	2.606	7.01	5 50	2.22	153.63
	4.032	314.45	321.80	....	193.75	314.31	314.38	2.606	7.42	5.70	2.36	153.85
C. & N. W. Ry. Co.....	4 044	314.15	323.68	....	193.56	314.05	314.10	2.605	9.58	7.30	3.05	150.69
	4.048	314.32	324.31	....	193 57	314.25	314.29	2 603	10.02	7.60	3.18	150.08
C. & N. W. Ry. Co...	3.992	313.59	321.62	....	192.70	312.50	312.55	2 607	9.07	7.03	2.90	151 24
	4.014	308.67	316.59	....	190.28	308.56	308.62	2.545	7 97	6.17	2 57	149.01
Duluth Brownstone Co......	3 976	306.06	319.60	319.98	189.55	306.85	306.450	2.621	13.530	10.37	4.415	146.54
	4.018	311.15	325.26	326.20	193.53	310.60	310.875	2.649	15.325	11.55	4.925	146.26
Dunnville Standstone	3.981	231.56	266.48	266.50	142.50	231.39	231.47	2.601	35.03	28.24	15 13	116.49
	3.830	237.30	273.10	273.44	145.40	237.20	237.30	2 582	36.14	28.28	15 22	115.55
Flag River Brownstone Co...	4.551	323.98	357.89	358.45	200.29	323.89	323.935	2 619	34.515	21.81	10 66	127 76
	4.466	317.86	351.10	351.93	196.88	317.70	317.780	2.628	34.150	22.02	10.74	128.01
Grover Red Standstone	about	150.90	158.06	158.06	93.72	150.85	150.875	2.639	7.185	11.16	4.76	146.34
	2.25	138.34	144.35	144.45	85.98	138.30	138.32	2.647	6.130	10.49	4.43	148.03
Port Wing Brownstone Co...	4.111	267.72	293.75	295.10	166.10	267.22	267.470	2.638	27.690	21.41	10 33	129.38
	4.007	264.72	291.85	292.11	163.86	264.75	264.735	2.624	27.375	21.87	10.34	128.75
R. D. Pike Quarry...........	4.293	294.65	327.35	327.35	182.70	294.59	294.62	2.632	32.73	22 62	11 11	127.13
	4.170	275.74	305.80	306 15	170.67	275.70	275.72	2.624	30.43	22.39	11.04	127.16
The Prentice Brownstone Co	4.029	289.05	314.75	315.20	180.20	289.85	289.450	2.649	25.750	19.07	8.89	133.80
	4.646	316.42	344.95	345.32	196.72	316.35	316.385	2 643	28.935	19.46	9.14	132 84
Washburn Stone Co..........	4.040	283.80	309.91	309.91	176.40	283.70	283.750	2.643	26.160	19.59	9.01	132.63
	4.138	289.19	315.02	315.42	179.68	289.03	289.135	2.641	26.285	19.33	9.068	132.96

TABLE VI.

Freezing and Thawing Tests.

Name of Quarry.	Location.	Dry weight in grams.	Dry weight after 35 days' exposure.	Loss in weight.	Loss per cent.	Average area of bearing faces.	First crack.	Ultimate strength of sample.	Ultimate strength in pounds per square inch.
GRANITE AND RHYOLITE.									
Amberg Granite Co.....	Athelstane...	355.585	355.45	0.135	.03	4.012	23,770	39,180	9,765
Amberg Granite Co.....	Athelstane...	349.55	349.47	0.08	.02	3 968	24,130	45,525	11,473
Berlin Granite Co	9 miles from Berlin......	300.68	300.68	None.	......	3.734	71,000	114,295	36,009
E. J. Nelson Granite Co	Berlin........	378.535	378.41	0.125	.03	4.310	126,100	159,590	37,027
E. J. Nelson Granite Co	Berlin	379.065	378.95	0.115	.03	4.208	91,000	118,950	28,505
French Granite Co	High Bridge .	369.525	369.50	0.025	.006	4.140	53,280	66,325	16,019
Granite Heights Co....	Gran. Heights	340.205	340.16	0.043	.01	3.962	58,730	84,530	21,335
Granite Heights Co....	Gran. Heights	327.305	327.15	0.153	.04	3.851	53,250	74,240	19,273
Jenks' Quarry	Irma	370.52	370.44	0.08	.02	4.323	41,280	65,710	15,200
Jenks' Quarry	Irma	368.13	367.95	0.18	.05	4.088	55,300	66,930	16,328
Leuthold's Quarry.....	Granite City.	364.59	364.51	0.08	.02	4.326	55,000	64,400	14,886
Milwaukee Monument Co..................	11 miles from Berlin......	373 65	373.61	0.04	.01	4.186	110,000	124,710	29,788
Milwaukee Monument Co....................	11 miles from Berlin......	370.12	370.04	0.08	02	4.129	140,000	140,000	33,906
Montello Granite Co ...	Montello.....	372.905	372.87	0 035	.01	4.194	147,000	149,140	35,568
Montello Granite Co ...	Montello.....	378 925	378.87	0.053	.01	4.268	117,000	147,375	34,530
New Hill O'Fair	Gran. Heights	343.245	343.050	0.195	.05	3.931	62,950	76,135	19,365
Pike River Granite Co.. (Gray.)	Amberg	304 285	304.30	None.	......	3.826	....	70,550	18,480
Pike River Granite Co.. (Red.)	Amberg	371.725	371.60	0.125	.03	4.239	96,100	96,270	22,446

TABLE VI.—Continued.

Freezing and Thawing Tests.

LIMESTONE.

Name of Quarry.	Location.	Dry weight in grams.	Dry weight after 35 days, exposure	Loss in weight.	Loss per cent.	Average area of bearing faces.	Position of cube in testing machine.	First crack.	Ultimate strength of sample.	Ultimate strength in lbs. per sq. inch.	Remarks.
Bauers' Quarry.......	Knowles......	174.1 176.35 60	174.10 176 06	0.035 0 54	.02 .30	2.54 2.56	Bed.... Edge ...	35,000 47,500	38,850 47,910	15,295 18,715	
Bridgeport Stone Quarry...............	Bridgeport...	131.20 135.05	131.20 135.09	No loss. No loss	No loss. No loss.	2.21 2.28	Edge ... Bed.....	12,340 21,570	12,340 21,570	5,581 9,470	
Gillen Stone Co.......	Duck Creek..	393.075	392.52	0.555	.14	4.092	Bed.....	105,000	116,000	28,392	
Laurie Stone Co......	Sturgeon Bay.	189.45 179.78	189.41 179.77	0.04 0.01	.02 .005	2.580 2.46	Bed..... Edge ...	....	40,850 63,275	15,833 25,721	
Lee Bros. Quarry.....	Genesee	152.545 159.635	152.57 159.65	No loss. No loss.	No loss. No loss.	2.20 2.26	Bed..... Edge..	 40,000	78,525 48,550	34,784 21,482	
Marblehead Lime and Stone Co	Marblehead..	166.79 172.85	166.85 172.85	No loss. No loss.	No loss. No loss.	2.44 2.54	Bed..... Edge ...	54,460 55,750	56,700 79,900	23,237 31,498	
Menominee Falls Co..	Lannon	181 005 177.785	181.02 177.89	No loss. No loss.	No loss. No loss.	2.48 2.52	Bed..... Edge ...	....	42,685 27,170	17,211 10,792	
Oenning & Gleson Quarry.............	Fountain City	140 27 134.09	140.25 134.01	0.02 0.08	.01 .06	2.38 2.20	Edge ... Bed	18,150	18,383 24,640	7,724 11,200	
Story Bros. Quarry...	Wauwatosa..	42.40 45.11	42.39 45.11	0.01 No loss.	.023 No loss.	.9995 0.9947	Bed..... Edge....	....	29,000 22,425	29,014 22,544	
Voree Stone Quarry...	Burlington...	346.755 336.61	347.32 336.28	No loss. 0.33	No loss. .09	4.1030 4.0750	Bed..... Bed.....	....	36,040 25,775	8,784 6,325	
Washington Stone Co.	Sturgeon Bay.	197.24 194.345	197.10 194.16	0.14 0.185	.07 .09	2.570 2.570	Edge.... Bed	23,000 42,500	30,490 46,820	11,863 18,023	Shape of cubes was very irregular.

TABLE VI.—Continued.

Freezing and Thawing Tests.

SANDSTONE.

Name of Quarry.	Location.	Dry weight in grams.	Dry weight after 35 days exposure.	Loss in weight.	Loss per cent.	Average area of bearing faces.	Position of cube in testing machine.	First crack.	Ultimate strength of sample.	Ultimate strength in lbs. per sq. inch.	Remarks
Argyle Brownst. Co...	Argyle........	246.29	244.76	1.53	.62	3.724	Bed	6,840	8,760	2,325	
		243.19	242.58	0.61	.25	3.790	Edge ...	7,390	8,020	2,116	
Ashland Brownst. Co.	Presque Isle..	265.795	265.15	0.645	.24	3.976	Bed	....	27,160	6,830	Good pyramids.
		272.235	271.93	0.305	.11	4.008	Edge ...	....	20,160	5,030	
Babcock & Smith.....	Houghton....	283.75	283.27	0.48	.17	4.040	Bed	16,090	16,325	4,040	
		289.135	288.80	0.335	.11	4.135	Edge ...	13,230	14,010	3,[illegible]89	
Bass Isl'd Br'wnst. Co	Bass Island..	366.85	366.47	0.38	.13	5.205	Bed	24,590	29,990	5,743	
		412.05	411.60	0.45	.10	5.302	Edge ...	....	20,140	3,874	
Bonder Quarry.......	Gr'nd Rapids	273.355	273.23	0.125	.047	3.887	Bed	28,800	35,120	9,036	
		302.185	302.10	0.085	.028	4.120	Edge ...	....	30,615	7,430	
Duluth Brownst. Co.	Fond du Lac.	306.45	305.60	0.85	.27	3.976	Edge ...	15,060	18,135	4,561	On several occasions after freezing small grains of sand were found scattered on the paper adjacent to the samples.
		310.875	310.45	0.425	.13	4.018	Bed	....	37,150	9,245	
Dunnville	Dunnville....	231.47	231.10	0.37	.16	3.981	Bed	....	18,220	4,578	
		337.30	237.00	0.30	.13	3.830	Edge ...	8,920	9,000	2,350	
Flag River Brownst...	Near Pt. Wing	323.933	323.45	0.483	.14	4.551	Bed	18,160	18,570	4,080	
		317.78	317.45	0.33	.10	4.466	Edge ...	10,530	12,420	2,781	
Grover Red Sandst...	LaValle.....	150.875	150.82	0.055	.036	2.46	Bed	....	19,170	7,793	Samples were not perfect.
		138.32	138.30	0.02	.015	2.36	Edge ...	....	10,595	4,489	
Pike's Quarry	Bayfield......	4.62	294.15	0.47	.16	4.293	Edge ...	9,740	10,490	2,440	
		275.72	275.43	0.29	.10	4.170	Bed	12,500	14,500	3,477	
Port Wing Quarry....	Port Wing ...	267.47	267.37	0.10	.037	4.111	Bed	21,750	21,750	5,290	
		264.735	264.11	0.625	.23	4.007	Edge ...	14,055	14,055	3,508	
Prentice Brownst. Co.	Houghton....	289.45	289.45	No loss.	No loss.	4.029	Edge ...	9,150	12,880	3,197	
		316.385	315.94	No loss.	No loss.	4.146	Bed	....	22,300	4,800	

TABLE VII.

Comparative Crushing Strength of the Fresh and Frozen Samples.[1]

Name of Quarry.	Location of quary.	No. of samples.	Crushing strength. Fresh samples.	No. of samples.	Crushing strength. Frozen	Difference.	Remarks.
GRANITE AND RHYOLITE.							
Amberg Granite Co.	Athelstane	4	19,988	2	10,619	9,369	The samples had bearing faces carefully prepared but the sides were somewhat irregular.
Berlin Granite Co.	Near Berlin	1	24,800	1	36,009	(11,209)	Samples were not equally perfect.
E. J. Nelson Granite Co	Berlin	2	45,841	2	32,766	13,075	Samples were not equally perfect.
French Granite Co	High Bridge	1	24,229	1	16,019	8,210	
Granite Heights Co	Granite H'g'a.	2	22,507	2	20,306	2,201	
Jenks' Quarry	Irma	3	18,023	2	15,764	2,259	
Leuthold's Quarry	Granite City.	1	25,000	1	14,886	10,114	
Milwaukee Monument Co	Near Berlin	3	34,640	2	31,844	2,796	
Montello Granite Co.	Montello	3	38,244	2	35,045	3,199	
New Hill O'Fair	Granite H'g'a	1	27,262	1	19,368	7,894	
Pike River Granite Co	Amberg (Gray)	1	27,887	1	18,439	9,448	Samples were not equally perfect.
	(Red)	1	18,237	1	22,445	(4,208)	
LIMESTONE.							
Bauer's Quarry	Knowles	2	30,680	2	17,005	13,675	
Bridgeport Stone Quarry	Bridgeport	3	8,098	2	7,527	571	
Gillen Stone Co.	Duck Creek	3	24,522	1	28,392	(3,870)	Fresh samples were removed from 100,000 to 300,000 lbs. machine before they were crushed. This accounts for low results.
Laurie Stone Co	Sturgeon Bay	2	35,970	2	20,777	15,193	
Lee Bros	Genesee	2	32,992	2	28,133	4,859	
Marblehead Lime and Stone Co	Marblehead	2	41,620	2	27,366	14,254	The frozen samples were not as perfect as the fresh ones.
Menominee Falls Co.	Lannon	2	32,710	2	13,996	18,714	Frozen samples were smaller and more irregular than fresh ones.
Oenning & Giesen	Fountain City	2	8,799	2	9,462	(663)	
Story Bros	Wauwatosa	......	18,477	2	25,779	(6,302)	Results in first column were with hammer dressed samples. Those in last column were sawn samples.
Voree Quarry	Burlington	2	12,827	2	7,554	5,273	
Washington Stone Co.	Sturgeon Bay	7	30,745	2	14,943	15,802	Samples used in obtaining last results were rough and unsatisfactory.

[1] Parentheses indicate that the frozen samples averaged a higher crushing strength than the fresh ones.

TABLE VII. Continued.

Comparative Crushing Strength of the Fresh and Frozen Samples.

Name of Quarry.	Location of quarry.	No. of samples.	Crushing strength. Fresh samples.	No. of samples.	Crushing strength. Frozen.	Difference.	Remarks.
			SANDSTONE.				
Argyle Brownstone Co	Argyle........	......	4,173	2	2,220	1,953	
Ashland Brownstone Co..................	Presque Isle.	2	5,495	2	5,930	(435)	All sandstone results are averages of two samples, one of which was crushed on the bed and the other on edge.
Babcock and Smith ..	Houghton....	2	5,421	2	3,714	1,707	
Bass Island Brownstone Co	Bass Island ..	2	4,718	2	4,808	(90)	
Duluth Brownst. Co.	Fond du Lac.	2	5,991	2	6,903	(912)	
Dunnville Quarry.....	Dunnville....	......	2,722	2	3,464	(742)	
Grover Red Sandstone Quarry..............	La Valle	2	12,405	2	6,141	6,261	Frozen samples were not perfectly shaped
Pike's Quarry	Bayfield......	2	4,040	2	2,958	1,082	
Port Wing Quarry....	Port Wing ...	2	5,329	2	4,399	930	
Prentice Brownstone Co	Houghton....	2	4,319	2	3,993	326	

TABLE VIII.

Effect of Sulphurous Acid gas in a Moist Atmosphere on Samples of Limestone. Time, 44 Days.

Quarry.	Weight at 110° C. before treatment. In grams.	Weight at 110° C. after treatment. In grams.	Remarks.
Bauer's Quarry	181.61	181.54	This cube was colored yellow. Over almost the entire surface a clear crystalline precipitate of magnesium salts had formed. In some places it was a mere film, in other places it was in considerable sized crystals, especially on one corner. The rougher the face the yellower the colors
Bridgeport	39.93	40.00	Shows slight corrosive action and yellow coloring.
Gillen Stone Co	44.97	44.94	Irregular spots and patches of yellow. Very slightly corroded.
Laurie Stone Co	48.72	48.68	Slightly corroded and shows thin glistening precipate in patches over the surface. Yellow along cracks and in irregular patches.
Lee Brothers	176.75	177.15	Crystals not shown. Faces were slightly corroded and had a faint yellow color distributed in small irregular spots and patches.
Marblehead Lime and Stone Co	48.70	48.77	Shows glistening precipitate on surface. Some parts apparently very slightly corroded. A faint yellow color is given to certain parts of the face.
Menominee Falls Co	48.25	48.43	Shows a very faint yellow coloring and irregular corrosion.
Genning & Giesen	38.94	39.04	Yellow discoloration. Some small corroded spots.
Story Brothers	49.11	49.16	Slight etching. Faint discoloration.
Voree	35.20	34.80	Slight corrosion and glistening precipitation on surface. Slightly discolored.
Washington Stone Co	51.30	51.25	Discolored along cracks and beds and in irregular areas. Crystalline precipitate magnesium salts on surface.

TABLE IX.

Effect of Carbonic Acid Gas in a Moist Atmosphere on Samples of Limestone. Time, 44 Days.

Quarry.	Weight at 110° C. before treatment. In grams.	Weight at 110° C. after treatment. In grams.	Remarks.
Bauer's Quarry	177.65	177.61	
Bridgeport Stone Quarry	129.35	129.32	The samples gave no evidence of deterioration.
Gillen Stone Co	43.36	43.35	
Laurie Stone Co	49.95	49.92	
Lee Brothers' Quarry	162.77	162.75	
Marblehead Lime and Stone Co	46.40	46.41	
Menominee Falls Quarry Co	42.07	42.05	
Oenning and Giesen	41.32	41.31	
Story Brothers	46.49	46.47	
Voree Quarry	34.84	34.80	
Washington Stone Co	53.81	53.79	

TABLE X.

Effects of High Temperature.

Name of quarry.	Location.	Approximate length of edge of cube in inches.	Temperature at which samples were essentially destroyed.	Remarks.
GRANITE AND RHYOLITE.				
			° F.	
Amberg Granite Co ..	Athelstane...	2	1,200-1,500	Cracked at 1,000° F.
R. J. Nelson Gran. Co	Berlin........	2	1,200-1,500	At 1,200° F. the sample was cracked in several places.
Granite Heights Co..	Gran. H'ghts.	2	1,500	Sample was suddenly cooled and thereby the corners flaked off, as shown in the illustration. (Pl. LVII.)
Jenks' Quarry	Irma	2	1,200-1,500	The sample changed to a pinkish color. When struck with a hammer or scratched it emitted the sound peculiar to a burnt brick. Not totally destroyed.
Milwaukee Mon. Co..	Near Berlin..	2	1,500	Same peculiar ring. Not totally destroyed.
Montello Granite Co.	Montello.....	2	1,200-1,500	Cracked in two directions across the sample. Characteristic ring.
LIMESTONE.				
Bauer's Quarry.......	Knowles	1½	1,200-1,400	Calcination was apparently slower than in other samples.
Bridgeport Stone.....	Bridgeport...	1½	1,200-1,400	Calcinated.
Gillen Stone Co.......	Duck Creek..	2	1,200-1,400	Color, bluish white. Some cracking along the bed. Calcinated.
Laurie Stone Co......	Sturgeon Bay	1½	1,200-1,400	When suddenly cooled the sample flaked at the corners as shown in the illustration.
Lee Bros........	Genesee......	1½	1,200-1,400	Not injured except somewhat calcinated along edges.
Marblehead, Lime & Stone Co...........	Marblehead..	1½	1,200-1,400	Calcination extended apparently only to a depth of about ¼ inch, but after being exposed to the air for several weeks almost the entire sample crumbled.
Menominee Falls Co.	Lannon	1½	1,200-1,400	
Oenning & Giesen	Fountain City	1½	1,200-1,400	
Story Bros............	Wauwatosa..	1	1,200-1,400	When the sample was suddenly cooled the flaking of the corners was very marked.
Voree Stone Quarry..	Burlington...	2	1,200-1,400	At 1,200° the sample took on a reddish color. Cracked and calcinated.
Washington Stone Co.	Sturgeon Bay	1½	1,200-1,400	Laminations were intensified by heat of 800°. At 1,200° the sample showed signs of calcination on corners and edges.

TABLE X.—Continued.

Effects of High Temperature.

Name of quarry.	Location.	Approximate length of edge of cube in inches.	Temperature at which samples were essentially destroyed.	Remarks.
		SANDSTONE.		
			° F.	
Bass Island Brownst..	Bass Island..	2	1,200	One crack. Sound emitted by scratching is like that heard when brick is scratched. Color changed to a lighter red. Strength gone.
Washburn Co	Houghton....	2	1,200	
			° F.	
Argyle Brownst.......	Argyle........	2	1,200	Sample crumbled upon handling. Totally destroyed.
Ashland Brownst.	Presque Isle.	2	1,200	Hardness about that of a soft brick.
C. & N. W. Ry.........	Ablemans....	2	1,400	At 1,200° the sample had lost considerable strength, but was not totally destroyed.
Duluth Brownst.	Fond du Lac.	2	1,500	Apparently not destroyed, but emitted the sound of a brick when scratched.
Dunnville	Dunnville....	2	1,200	One crack produced. Crumbled between the fingers. Yellowish brown color.
Flag River Brownst..	Near Pt. Wing	1½	1,200	Strength mostly gone.
Grover Red Sandst'ne	La Valle......	1½	1,100	Strength gone. Crumbled. Color changed to a very dark red. Somewhat injured at 1,000° F.
Port Wing............	Port Wing...	2	1,200	At this temperature the sample remained in perfect shape, but strength was partly gone.
Prentice Brownst....	Houghton....	2	1,200	Strength gone. Crumbles. Color slightly lighter red.

Table XI.

Specific Gravity and Ratio of Absorption of Building Stone Occurring Outside of Wisconsin.

Location.	Specific gravity.	Ratio of absorption.	Per cent. of loss in weight by freezing.	Remarks.
GRANITE.				
[1] E. St. Cloud, Minn......	2.70	2.59	.02	Absorption after 4 days' soak'g.
[1] Sauk Rapids, Minn.....	2.71	0.19	.03	Absorption after 4 days' soak'g.
[1] E. St. Cloud, Minn......	2.63	0.08	.18	Absorption after 4 days' soak'g.
[1] Watab, Minn............	2.73	2.35	.02	Absorption after 4 days' soak'g.
[2] Fourche Mountain, Ark.	2.635	....	....	
[2] Fourche Mountain, Ark.	2.642	1-1673	....	Absorption obtained by soaking until an approximately constant weight was obtained.
[3] Staten Island, N. Y.....	2.861	1-4530	.. ..	
[3] Jersey Heights. N. J....	3.030	....	....	Quantitative results of alternate freezing and thawing are very few.
[3] Dix Island, Me..........	2.635	....	....	
[3] Quincy, Mass...........	2.695	....	....	
[3] Grindstone Island, N. Y.	2.7139	1.55	....	
[3] Keeseville, N. Y.........	2.7551	.066	....	
[3] Hallowell, Me...........	2.6519	.410	....	
[3] Hallowell, Me...........	2 6543	.370	....	
[4] Fox Island, Me..........	2.642	1-680	....	
[4] Stark, N. H..............	2.631	1-534	....	
[4] Concord, N. H...........	2.636	1-778	....	
[4] Barre, Vt................	2.651	1-720	....	
Richmond, Va.......... ..	2.727	1-398	....	
MARBLE, LIMESTONE, AND DOLOMITE.				
[1] Frontenac, Minn........	2.63	3.49	0.11	
[1] Stillwater, Minn.........	2.77	2.19	0.05	
[1] Winona, Minn...........	2.67	2.88	0.05	
[1] Kasota, Minn............	2 61	2.51	0.30	
[1] Minneapolis, Minn......	2 77	2.36	2.21	
[7] St. Joe, Ark. (marble) ..	2.712	0.34	....	
[7] St. Joe, Ark. (marble) ..	2.697	0.33	....	

[1] Geol. & Nat'l Hist. Sur. of Minn., final report, Vol. I, p. 196.
[2] Ann. Rept. Ark. Geol. Sur., Vol. II, 1890, pp. 48-50, by J. F. Williams.
[3] Bull. of the N. Y. State Museum, Vol. II, No. 10, p. 358, by Prof. J. C. Smock.
[4] Notes on Building Stones, Vermont, p. 8, by Dr. H. A. Cutting.
[7] Ann. Rept. Ark. Geol. Sur., 1890, Vol. IV, pp. 210-11.—T. C. Hopkins.

TABLE XI.— Continued.

Specific Gravity and Ratio of Absorption of Building Stone Occurring Outside of Wisconsin.

Location.	Specific gravity.	Ratio of absorption.	Per cent. of loss in weight by freez-	Remarks.
MARBLE, LIMESTONE, AND DOLOMITE—continued.				
[7] Marble City, Ark. (m'ble)	2.691	0.57	....	
[3] Sandy Hill, N. Y.	2.7641	0.140	....	
[3] Plattsburg, N. Y	2.7096	0.145	....	
[3] Auburn, N. Y.	2.7230	0.120	....	
[3] Williamsville, N. Y.	2.7079	0.160	....	
[4] Baltimore, Md.	2.917	1-340	....	
[4] Bedford, Ind.	2.478	1-280	....	
[4] Hamilton Co., O.	2.204	1-28	....	
[4] Springfield, Penn.	2.666	1-280	....	
[5] Bedford. Ind.	2.47	1-23	....	
[5] Salem, Ind	2.51	1-31	....	
SANDSTONE.				
[1] Hinckley, Minn.	2.47	4.88	0.08	
[1] Dresbach, Minn.	3.38	11.48	0.06	
[1] Jordan, Minn.	2.34	12.69	0.06	
[1] Dakota, Minn.	2.38	11.08	0.09	
[6] Waltonville, Pa.	2.66	1-87	....	
[6] Lumberville, Pa.	2.60	1-68	....	
[6] Portland, Conn.	2.35	1-40	....	Test made at Watertown Arsenal.
[6] E. Longmeadow, Mass.	2.49	1-19	....	Test made at Watertown Arsenal (Dec., 1883).
[6] Marquette, Mich.	2.29	1-32	....	Test made by Gen. Gilmore.
[6] Marquette, Mich.	2.16	1-20	....	Test made by Gen. Gilmore.
[6] Portage Entry, Mich.	2.54	1-11	....	Figures from stone, June, 189
[3] Potsdam, N. Y.	2.604	2.08	....	
[3] Hulberton, N. Y.	2.5852	2.48	....	
[3] Portage, N. Y.	2.6969	2.97	....	
[3] Nova Scotia, Can.	2.6236	18.07	....	
[4] Salem, Md.	2.452	1-24	....	
[4] Cincinnati, O.	2.188	1-23	....	
[4] Cheat River, W. Va.	2.632	1-80	....	
[4] Cleveland, O.	2.210	1-22	....	

[1 2 3 4 7] See foot notes p. 413.
[5] 21st Ann. Rept. on The Geology and Natural Resources of Indiana, p. 315.
[6] App. Ann. Rept. Pa. State College, 1896, p. 30. (Brownstones

Table XII.

Crushing Strength in Pounds per sq. in. of Building Stone Occurring Outside of Wisconsin.

Location of stone.	Compressive strength in pounds per square inch.	Authority.
GRANITE.		
East St. Cloud, Minn........	28,000	Geological Survey of Minnesota, Vol I., p. 196.
Sauk Rapids, Minn..	21,500	Geological Survey of Minnesota, Vol. I., p. 196.
Beaver Bay, Minn	26,500	Geological Survey of Minnesota, Vol. I., p. 196.
Fourche Mountain, Ark....	28,700	Annual Report Arkansas Geological Survey, 1890, Vol. II., p. 44. (The results computed for the last column, as given in the Arkansas report above referred to, are thought to be erroneous, owing to the fact that the formula worked out by Gen. Gilmore has been shown to be of no value.)
Fourche Mountain, Ark....	21,500	Annual Report Arkansas Geological Survey, 1890, Vol. II., p. 44.
Fourche Mountain, Ark....	22,900	Annual Report Arkansas Geological Survey, 1890, Vol. II., p. 44.
Fourche Mountain, Ark....	29,000	Annual Report Arkansas Geological Survey, 1890, Vol. II., p. 44.
Fourche Mountain, Ark....	27,900	Annual Report Arkansas Geological Survey, 1890, Vol. II., p. 44.
Saratoga, N. Y.............	25,600	39th Annual Report of the New York Museum of Natural History, p. 220.
Saratoga, N. Y.............	16,800	39th Annual Report of the New York Museum of Natural History, p. 220.
Little Rock, Ark	22,388	Tests of Metals. Government Rept., 1895, p. 320.
Little Rock, Ark	20,025	Tests of Metals. Government Rept., 1895, p. 320.
Little Rock, Ark	18,577	Tests of Metals. Government Rept., 1895, p. 320.
Little Rock, Ark	17,407	Tests of Metals. Government Rept., 1895, p. 320.
Little Rock, Ark	24,653	Tests of Metals. Government Rept., 1895, p. 320.
Little Rock, Ark	20,363	Tests of Metals. Government Rept., 1895, p. 320.
Little Rock, Ark	27,518	Tests of Metals. Government Rept., 1895, p. 320.
Chesterfield county, Va....	15,350	Tests of Metals. Government Rept., 1895, p. 320.
Korah, Va	23,446	Tests of Metals. Government Rept., 1895, p. 320.
Milbridge, Me	19,917	Tests of Metals. Government Rept., 1895, pp. 319, 320.
Rockville, Minn	18,121	Tests of Metals. Government Rept., 1895, pp. 319, 320.
Exeter, Cal	20,368	Tests of Metals. Government Rept., 1895, pp. 319, 320.
Exeter, Cal	24,746	Tests of Metals. Government Rept., 1895, pp. 319, 320.
MARBLE.		
Rutland, Vt................	11,892	Tests of Metals. Government Rept., 1895, pp. 319, 320.
Rutland, Vt	13,884	Tests of Metals. Government Rept., 1895, pp. 319, 320.
Mountain, Vt...............	12,883	Tests of Metals. Government Rept., 1895, pp. 319, 320.

TABLE XII.—Continued.

Crushing Strength in Pounds per sq. in. of Building Stone Occurring Outside of Wisconsin.

Location of stone.	Compressive strength in pounds per square i	Authority.
	MARBLE.—continued.	
Sutherland Falls, Vt.......	16,156	Tests of Metals. Government Rept., 1895, pp. 319, 320.
De Kalb, N. Y	13,733	Tests of Metals. Government Rept., 1895, pp. 319, 320.
De Kalb, N. Y	10,478	Tests of Metals. Government Rept., 1895, pp. 319, 320.
De Kalb, N. Y	12,004	Tests of Metals. Government Rept., 1895, pp. 319, 320.
De Kalb, N. Y	13,772	Tests of Metals. Government Rept., 1895, pp. 319, 320.
Colton, Cal.................	17,783	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
Canaan, Conn	5,812	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
St. Joe, Ark.................	17,835	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
St. Joe, Ark.................	10,447	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
St. Joe, Ark.................	8,984	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
St. Joe, Ark.................	11,265	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
	LIMESTONE.	
Isle La Mott, Vt............	14,622	Tests of Metals. Gov. Rept., 1895, pp. 319, 320.
Beaver, Ark.....	20,581	Tests of Metals. Gov. Rept., 1895, pp. 319, 320.
Bowling Green, Ky.........	6,042	Tests of Metals. Gov. Rept., 1895, pp. 319, 320.
Wasioja, Minn.............	4,029	Tests of Metals. Gov. Rept., 1895, pp. 319, 320.
Wasioja, Minn..............	5,014	Tests of Metals. Gov. Rept., 1895, pp. 319, 320.
Ellettsville, Ind............	6,700	Report of State Geologist of Indiana for 1896, p. 313.
Ellettsvelle, Ind............	5,900	Report of State Geologist of Indiana for 1896, p. 313.
Bloomington, Ind...........	11,400	Report of State Geologist of Indiana for 1896, p. 313.
Bloomington, Ind...........	3,400	Report of State Geologist of Indiana for 1896, p. 313.
Salem, Ind..................	6,900	Report of State Geologist of Indiana for 1896, p. 313.
Salem, Ind..................	11,700	Report of State Geologist of Indiana for 1896, p. 313.
Bedford, Ind...............	3,400	Report of State Geologist of Indiana for 1896, p. 313.
Bedford, Ind...............	9,700	Report of State Geologist of Indiana for 1896, p. 313.
Stinesville, Ind............	6,600	Report of State Geologist of Indiana for 1896, p. 313.
Stinesville, Ind............	4,100	Report of State Geologist of Indiana for 1896, p. 313.
Average of 17 cubes of Bedford Oolitic limestone ...	4,826.7	Report of State Geologist of Indiana for 1896, p. 317.
Lemont, Ill.................	12,000	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.

TABLE XII.—Continued.

Crushing Strength in Pounds per sq. in. of Building Stone Occurring Outside of Wisconsin.

Location of stone.	Compressive strength in pounds per square inch.	Authority.
LIMESTONE.—continued.		
Joliet, Ill.	14,775	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
Quincy, Ill.	9,687	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
Billingsville, Mo	6,650	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
Junction City, Kan.	2,996	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
Junction City, Kan.	3,350	An. Rept. Arkansas Geol. Sur., Vol. IV., 1890, p. 210.
Kelly Island, L. Erie	11,910	Tests of Metals. Gov. Rept., 1892, pp. 607-609.
Kelly Island, L. Erie	12,890	Tests of Metals. Gov. Rept., 1892, pp. 607-609.
Kelly Island, L. Erie	14,500	Tests of Metals. Gov. Rept., 1892, pp. 607-609.
Kelly Island, L. Erie	8,290	Tests of Metals. Gov. Rept., 1892, pp. 607-609.
Stone City, Iowa	11,250	Minnesota Geological Survey Report, Vol. I., p. 201.
Frontenac, Minn.	11,250	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
Stillwater, Minn	25,000	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
Stillwater, Minn	10,750	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
Winona, Minn	16,250	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
Red Wing, Minn	23,000	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
Kasota, Minn	18,500	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
Minneapolis, Minn.	21,750	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
Kasota, Minn	18,000	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
Fountain, Minn	26,250	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
St. Paul, Minn	19,500	Minnesota Geological Survey Report, Vol. I., pp. 196-201.
Tribes Hill, N. Y	25,022	39th. Ann. Rept. of the N. Y. Museum of Nat'l Hist., p. 220.
Tribes Hill, N. Y	24,622	39th Ann. Rept. of the N. Y. Museum of Nat'l Hist., p. 220.
Cobleskill, N. Y	27,407	39th Ann. Rept. of the N. Y. Museum of Nat'l Hist., p. 220.
Cobleskill, N. Y	21,066	39th Ann. Rept. of the N. Y. Museum of Nat'l Hist., p. 220.
SANDSTONE.		
Hinckley, Minn	19,000	Report of the Geol. Survey of Minn., Vol. I, p. 196.
Dresbach, Minn	6,500	Report of the Geol. Survey of Minn., Vol. I, p. 196.
Dakota, Minn	4,750	Report of the Geol. Survey of Minn., Vol. I, p. 196.
Birdsboro, Penn	11,448	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Waltonville, Penn	14,753	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.

TABLE XII.—Continued.

Crushing Strength in Pounds per sq. in. of Building Stone Occurring Outside of Wisconsin.

Location of stone.	Compressive strenth in pounds per square inch.	Authority.
SANDSTONE.—Continued.		
Waltonville, Penn	14,000	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Waltonville, Penn	12,730	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Waltonville, Penn	13,100	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Lumberville, Penn	19,895	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Laurel Run, Penn	22,250	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Laurel Run, Penn	17,600	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
White Haven, Penn	29,252	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Portland, Conn	12,580	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Middletown, Conn	6,250	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Cromwell, Conn	16,894	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
E. Longmeadow, Mass	12,210	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
E. Longmeadow, Mass	10,274	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Medina, N. Y	16,081	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Little Falls, N. J	9,500	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
St. Anthony, Ind	3,000	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Marquette, Mich	5,992	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Marquette, Mich	3,800	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Portage Entry, Mich	6,350	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
L'Anse, Mich	10,645	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Fond du Lac, Minn	8,750	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Kettle River, Minn	11,547	Brownstones of Pennsylvania, Appendix to Ann. Rept. Penn. State College, 1896, p. 54.
Riverside, Ind	6,045	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
Riverside, Ind	6,100	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
Riverside, Ind	6,800	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
Worthy, Ind	6,825	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
Berea, Ohio	11,213	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
Cleveland, Ohio	6,800	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
Cromwell, Conn	16,894	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
Gunnison, Colo	5,250	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
Coal Creek, Colo	2,879	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
Portland, Conn	4,945	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.

TABLE XII.—Continued.

Crushing Strength in Pounds per sq. in. of Building Stone Occurring Outside of Wisconsin.

Location of stone.	Compressive strength in pounds per square inch.	Authority.
	SANDSTONE.—Continued.	
Cleveland, O.	6,800	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
N. Amherst, O.	5,450	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl Resources, p. 323.
Angel Island, Cal.	4,574	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.
San Jose, Cal.	2,400	20th Ann. Rept. of Indiana, Dept. of Geol. and Natl. Resources, p. 323.

TABLE XIII.

Chemical Analyses of Wisconsin Building Stones.

Kind of rock and location.	SiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	$CaCO_3$	MgO	$MgCO_3$	K_2O	Na_2O	MnO	Water	Total.	Authority.
Granite (Wausau.)	76.54	13.82	1.62	....	0.85	....	0.01	....	2.81	4.32	....	0.20	99.67	W. W. Daniells.
Granite (Athelstane.)	66.10	20.82	1.52	2.17	1.57	....	0.95	....	3.48	2.94	....	0.54	100.09	W. W. Daniells.
Granite (Moutello.)	75.40	11.34	4.16	....	.90	....	....	....	6.44	1.76	....	....	100.00	F. G. Weichmann.
Granite (Waushara.)	74.62	10.01	3.85	1.72	2.43	....	0.33	....	3.38	3.33	....	0.24	99.91	Samuel Weidman.
Rhyolite (Berlin.)	73.65	11.19	1.31	3.25	2.78	....	.51	....	1.86	3.74	....	0.44	99.23	Samuel Weidman.
Rhyolite (Utley.)	73.09	13.43	2.57	....	2.29	....	1.03	....	1.58	3.85	Trace.	0.72	98.56	Samuel Weidman.
Limestone (Duck Creek.)	3.17	1.93		....	....	49.97	....	44.58	....	....	....	....	99.67	W. W. Daniells.
Limestone (Genesee.)	6.32	1.02		....	....	50.96	....	41.75	....	....	....	....	100.05	W. W. Daniells.
Limestone (Knowles.)	0.022	0.005		....	....	54.74	....	45.07	....	....	....	....	99.837	W. W. Daniells.
Limestone (Marblehead.)	2.12	0.59		....	....	53.51	....	43.54	....	....	....	....	99.76	W. W. Daniells.
Limestone (Sturgeon Bay.)	1.09	0.33		....	....	54.42	....	44.17	....	....	....	....	100.01	W. W. Daniells.
Sandstone (Houghton.)	86.57	8.43	1.55	....	....	....	....	....	2.36	0.67	Trace.	....	99.58	W. W. Daniells.
Sandstone (Port Wing.)	89.33	6.05	1.41	....	Trace.	....	Trace.	....	2.12	0.59	....	....	99.50	W. W. Daniells.
Sandstone (Ablemans.)	98.64	1.10		....	....	....	....	....	....	....	....	....	99.74	W. W. Daniells.

CHAPTER XI.

CONCLUSION.

The controlling factor in the successful operation of a quarry is apparently not the intrinsic value of the stone, but rather its market price. People, as a rule, and oftimes builders and contractors, are unfamiliar with those qualities of a stone which make it suitable for particular uses. This sometimes leads to the use of an inferior stone, in an attempt to minimize the cost. The actual cost of a stone dressed ready for use depends upon (1) the ease of quarrying, in blocks of the form demanded, (2) the facility with which the stone can be dressed, and (3) the cost of transportation. The price of a stone will not be altogether established by these factors, but will be conditioned by its beauty, susceptibility for taking a fine finish, and upon its reputation. Whether the stone is sold in the rough or dressed, will depend upon which brings the owner the greatest margin of profit.

The popular fancy for building stone changes at intervals from light to dark colored stone, and vice versa. This demand has an appreciable effect upon the market price of the two great classes of light and dark colored stone. When light colored stone is in demand, operators in dark colored stone are often obliged to lower the price of their product in order to retain their hold upon the market.

When a stone has a wide and continuous sale for twenty or twenty-five years, it is often said to have a "reputation." An inferior stone sometimes gains a reputation, on account of which it commands a better price than one which has undoubtedly greater value. Popular fancy and reputation often have no

relation to the quality of the stone. The use of a stone does not always depend upon its suitability to the structure in which it is placed.

As noted above, the ease with which a stone is quarried influences its price. The position of the stone in the quarry, the percentage of waste, the facilities for quarrying, and the wages paid the employees all influence the price of the stone. If the desirable stone is at or near the top of the quarry, its removal is much less expensive than when it is some distance below the surface. Quarries are frequently abandoned on account of the heavy stripping of soil and rip-rap beneath which the salable stone is concealed. Occasionally the upper beds of the quarry can be utilized in such a manner as to pay for their removal. When this can be done the depth of stripping does not very largely influence the price of the stone, but, other things being equal, the cost of quarrying may be said to vary as the stripping.

It is very seldom that all the stone, even of the best beds, can be sold as No. 1. Some of it is generally inferior in quality, and must be classified accordingly. The price of the stone will be to a certain extent influenced by this condition.

The facilities at hand for quarrying affect the price of the stone in two ways: (1) Adequate facilities will insure the most rapid removal of the stone at a minimum expense to the operator. (2) Through the use of modern appliances less waste is occasioned and the stone is better preserved. It is true that the investment is larger, but this is more than compensated for by the lessened cost of operating and the increased value of the stone.

The wages paid employees also affect the price of the stone. A large part of the value of a stone is in the labor placed upon it. A difference of twenty-five or fifty cents per day in the wages of the employees will influence very decidedly the cost of the product.

Turning from the conditions influencing the price of the quarried stone in the rough to those of the dressed stone, we note that usually the cost of cutting and dressing is by far the largest

factor in its price. There is a great difference in the facility with which the stone from different quarries can be cut and dressed, and the stone must bring a correspondingly higher price if operations are continued. It should also be observed that a stone does not take all the different dressings with equal ease, and that, of two different stones one may take a bush hammered finish more easily than the other takes a rock face finish. The difficulty with which certain stones dress frequently excludes them from the market, except for the finest kind of work. The cost of dressing is of course influenced by the price of labor, and an increase of twenty-five or fifty cents a day in wages may increase the price of the stone sufficiently to make it unsalable.

The price of labor, both skilled and unskilled, is lower in the eastern than it is in the western states. The immigrants from foreign countries are poured out upon the New England coast and the competition for employment is so much greater that it results in a lowering of prices. Labor is such a large item in the working of stone, that any difference will necessarily affect materially the market price of the stone.

The cost of transportation may considerably increase the price of stone. The extent to which this occurs depends upon the facilities, the rate, and distance from the market. If the stone has to be carted some distance by team to the nearest depot, the expense will be greater than if it were transported by rail. Further, the railroad rates are not uniform and the distance to market varies greatly.

The freight rates depend upon the company, the amount of competition, and the length of haul. Where there are two or more competing roads the rates are uniformly lower than where there is only one. Where there is only one line the rates are sometimes held so high as to almost exclude the possibility of operating the quarry. As a rule, the rates granted by Wisconsin roads show but little unfair discrimination. The companies recognize the fact that the prosperity of the quarrying industry contributes largely to their own prosperity, and that any extortionate rates will eventually react to their injury. Nevertheless

the quarry owners in the eastern and central parts of the United States have an advantage over the western quarry owners in relatively lower rates of transportation. The difference in rates is largely occasioned by the competition between the roads, but the greater distance which the stone has to be transported to the western market compensates to some extent for the lower rates. Nevertheless, these differences in rates assist the eastern quarrymen very materially in placing their product on the western market.

In a new country quarries are generally opened on a small scale. Most of the work is done by hand, and the operator soon finds himself at a very considerable disadvantage in competition with better equipped concerns. The quarries of the eastern states have been operated for much the longer time, and all the improved machinery necessary for the successful development of the industry has been taken advantage of. As the demand for stone in the west increases, and people attain a better appreciation of the value of the home product, the quarries of Wisconsin will be better equipped and the price of stone wil be correspondingly lowered.

In a number of instances in Wisconsin, the inaccessibility of the quarries has been the greatest hindrance to their successful development. A number of the quarries are from five to nine miles from any railroad. and the stone has to be hauled the entire distance by team. This naturally increases the price of the stone, and is a decided hinderance to the successful operation of the quarries.

The tables in Chapter VIII., which give the comparative crushing strength of stone from Wisconsin and other states are very favorable to Wisconsin stone, showing that the state possesses limestone and granite, which are superior in crushing strength to any that has elsewhere been tested. The results of the tests on durability can hardly be compared with the tests made elsewhere, because the conditions under which the experiments at the various laboratories were performed are very different. The porosity tests, as has been previously shown, are only

valuable when the methods of obtaining the results are taken into consideration, and the size of the pore spaces are considered. No data could be obtained on the loss of strength occasioned by alternate freezing and thawing of samples from the quarries of other states. A few experiments have been performed to determine the loss in weight, but, as previously shown, these data have little significance.

The lithographs which accompany this report give an excellent idea of the variety and beauty of the Wisconsin building and ornamental stone. A comparison of the granites with those which are imported will convince one that for beauty and variety the Wisconsin product is unexcelled. A fair idea of the different tints of color in the brownstone of the Lake Superior region is given in Plates XXIII. and XXXIV. There are many other delicate tints of brown or reddish brown among the sandstone quarries of this region, which could not be shown in these plates. No additional comment is needed by way of comparison with the brownstones of other states.

The average person who reads this report will be surprised to learn how difficult it has been to bring the people to an appreciation of the beauty, adaptability, and value of the stone now quarried in Wisconsin. Many of the larger public buildings, as well as hundreds of private residences in this state, have been constructed out of imported stone, where native stone might equally as well have been substituted. The pleasure which some people feel in knowing that "imported" materials have been used, must be satisfied, and as long as the construction of our public buildings and monuments is dominated by this sentiment, granite will continue to be shipped from Scotland, and brown sandstone and gray limestone will be imported from our sister states.

If a person desires stone of the best quality, he must pay more for it than he would for an inferior quality. Yet there are contractors who expect the best class of stone from one locality at the same price that they can obtain inferior stone from other localities. In the construction of public buildings the appropriations are oftimes too small to permit the use of the best ma-

terials. Likewise, in private buildings the contractor is often controlled in his selection of stone by the limited amount of money at his disposal.

Monuments are frequently erected, in cemeteries, on which the inscriptions will last but a few centuries. The real value of such a monument is thus lost. Monuments should stand uninjured for centuries, if they fulfill the meaning of the term, and irrespective of cost they should be built out of the most durable stone. Rather sacrifice a portion of the ornamentation than use a less durable stone. Marble has been used very extensively in past years throughout the country, but at the present time it is sold mainly in the rural districts. It has been very largely supplanted by granite, and it now becomes necessary for the purchaser of a monument to distinguish between the different kinds of granite and to know which one will serve his purpose best. As already seen, the Wisconsin granites are unsurpassed by those of any other country in durability, variety, and beauty, and from among them a desire for a monument of almost any tint, which will be durable, may be satisfied.

Nearly everywhere in this country one finds that in the great structures durability is sacrificed for cheapness. Men are controlled by their wealth. Pretentious structures are erected out of cheap material, which last only one or perhaps two generations, when they have to be replaced by new ones. The only value in this is in furnishing employment to workmen. The total wealth of the country is always decreased by the use of poor materials. The time is coming when men will consider more the element of durability, and temporary structures will be erected only in the newly developed sections of the country.

In the colder portions of the continent it is necessary to provide warmth as well as beauty, strength, and durability. In the more moderate climates this consideration does not enter into the construction of buildings, and for this reason many of the buildings in the south differ strikingly from those of the colder northern regions. It should also be remembered that environment conditions very largely the durability of a stone.

A stone which has effectually withstood the destructive agencies of one climate may decay very rapidly under new climatic conditions. This is one reason why it is sometimes unsafe to use a stone in a different climate from the one in which it is quarried.

The stone quarry industry in Wisconsin has not yet reached a stage of development corresponding to that of the quarries of the eastern states. In many places the industry is in its infancy, and the question comes to us, how can we best promote its development in Wisconsin. The fact that a larger part of the value of a stone is in the labor which is placed upon it, makes it one of the most important industries for the laboring class. The industry should receive a fair share of attention by the people of the state, and should be recognized in a public way. In the first place, a sentiment should be inaugurated which favors the use of native stone in the construction of all buildings within the state where the stone is equally good and desirable for such purposes. In the second place, the quarry operators should carefully grade the stone which they sell, permitting the use of only the best quality in positions where inferior stone will prove disastrous to the trade. Third, unnatural competition, which results in the sale of inferior stone for a better grade, as occurred in the brownstone industry a few years ago, should stop. Fourth, the quarries should be better and more fully equipped with improved machinery. In this way stone might be placed on the market at a much lower rate and in better shape than it is at the present time. Finally, the people of the state ought to have a better appreciation of what is meant by good building stone. They ought to know that often a cheap stone eventually proves more expensive than one which brings a higher price. The public ought not to be satisfied to erect public buildings out of cheap stone, which is often quarried close at hand. They should demand a good stone, one which is strong and durable.

If these principles were carefully adhered to, the future of our stone industry would be practically assured. At least it would be placed upon a solid basis, and the operators would be

in a position to know their position with reference to the demands of the people. Wood, brick, terra cotta, and iron have encroached upon the stone industry to such an extent that the natural increase has been greatly lessened. Before brick was largely used, the local quarries furnished a large amount of stone for the construction of buildings. In the early days, brick was more expensive than stone, but now, brick can be manufactured so very cheaply, that it has supplanted to a very large extent the use of stone. The relatively large amount of mortar which is necessary in the construction of a brick wall makes it much less durable than one built of stone. A building which is constructed for centuries of permanent use, ought not to be constructed out of brick. The appearance of a building is much less pleasing when it is built of brick than when it is constructed out of heavy stone masonry. It is to be hoped that in the future our larger school and college buildings, and in fact all structures which are built out of public money, will be of stone and not of brick. Our school, college and other public buildings should not be temporary structures, but should last for centuries, and it is to be hoped that in the future all such structures will have stone and not brick walls. Our works must assume more of the permanent and less of the temporary aspect, if our civilization is to be what the optimistically inclined predict of it.

Of not the least importance may be cited the educational value of beautiful architecture. The Cologne Cathedral educates the art of the entire city, and indeed of the world. The structures of the World's Columbian Exposition have educated the nation as to good architecture. All over the country the ideas there expressed are being copied. Every city which owns a truly fine building gets more than its cost in education. Such buildings as the Boston Public Library, Pittsburg Court House, and many others might be mentioned as notable instances. A visitor in a strange city always forms his estimate of the progressiveness of the people by the beauty of their public and private buildings.

We want permanent structures that are purely beautiful, so as to cultivate the people on the aesthetic side.

PART III.

Appendix.

CHAPTER I.

COMPOSITION AND KINDS OF STONE.—ROCK STRUCTURES.

INTRODUCTION.

In order to understand thoroughly the relative value of different stones used for building, monumental, or other purposes, one should be familiar with the more common mineral substances which compose the more important kinds of rock. He should understand not only their mineralogical composition, but he should also be familiar with the conditions under which they were formed, and the changes which they have undergone since their formation.

To the geologist an elementary discussion of this nature is entirely superfluous, but for the benefit of those who have little or no knowledge of geology, it is thought best to insert at this place, a brief account of the common minerals, giving their composition and physical properties, by means of which they may be distinguished from one another. Following the description of the minerals, the more important rock types are discussed and characterized.

Any general statements that are made in these pages with reference to the importance, abundance, hardness, durability, etc., of different minerals or rocks, unless otherwise stated, refer to building stones as a class, and not to rocks in general.

COMPOSITION AND KINDS OF STONE.

MINERALS.

Any rock which may be picked up for examination is composed, as a rule, of several different minerals in a state of aggregation. We may separate from this rock any one of the

minerals of which it is composed and by chemical means ascertain that it, in turn, is made up of two or more substances known as elements. According to Dr. H. Erdman of Halle there are seventy-four known elements which combine in various ways to form all known matter. The eight most important, in order cf abundance, are as follows: oxygen, 47.13 per cent., silicon, 27.89 per cent., aluminum, 8.13 per cent., iron, 4.71 per cent., calcium, 3.53 per cent., sodium, 2.68 per cent., magnesium, 2.64 per cent., potassium, 2.35 per cent. Very few of the elements are found free or uncombined in nature. They generally exist in combination with one another forming what is known as a mineral substance. In the neighborhood of two thousand different combinations, known as mineral species, have been described and named. Many of them are very rare and constitute a very inconsiderable part of the earth's crust. More than 95 per cent. of the rocks considered in this report are composed of various combinations of fourteen minerals.

Minerals are distinguished from one another by their physical properties, crystallization, and chemical composition. The chemical composition can only be obtained by a chemical analysis. Every mineral that separates from a solution or a molten magma under conditions where the growth is unobstructed, assumes a definite crystal shape. All minerals, which occur in crystals, crystallize under one of six well defined systems. These systems are recognized, in individual minerals, by the number and relation of the plane surfaces which bound the crystals. Thus, if we are able to make out in any way the number of faces and their relation to one another on any mineral, we have a means of determining the mineral itself. As a rock constituent, however, it is seldom possible to determine the system to which a mineral belongs or its specie by the crystal faces. The crystal faces belonging to the minerals of most sedimentary rocks, are usually entirely wanting, and in many of the igneous rocks they are either very imperfect or entirely absent. The mineral individuals are often so small that they can only be distinguished with the aid of a microscope.

The outward crystal form is an expression of a definite internal structure. On account of this structure each mineral possess certain optical properties by means of which one can, with the aid of a compound microscope, determine the system to which it belongs, and ordinarily the mineral itself. In the determination of the crystallization of the minerals of a rock the microscope is an indispensable auxiliary.

The physical properties, among which are color, luster, hardness, cleavage, and streak, are also valuable aids in the ready determination of minerals.

The hardness of a mineral is relatively constant. For convenience all minerals are referred to a scale of hardness of ten units, composed of common or well known minerals, which are as follows: (1) talc; (2) gypsum; (3) calcite; (4) fluorite; (5) apatite; (6) orthoclase; (7) quartz; (8) topaz; (9) sapphire; and (10) diamond. The hardness of any mineral is determined by its ability to scratch the members of this scale. The degree of hardness is expressed by the number of the mineral in the scale, and minerals of intermediate hardness are expressed by fractions.

The capacity which some minerals have to part more readily in certain directions than in others is known as cleavage. A mineral may possess cleavage in one or several directions. It may be well developed in one mineral, and poorly developed in others. The presence of cleavage, its perfection, and its relation to the different faces of the crystal often furnish a valuable means of identification.

The streak is the color of the mineral when powdered, and in the case of the softer minerals is obtained by scratching a piece of porcelain with the mineral which is to be identified. As a means of determining the minerals of building stones, this quality is not important except perhaps in two or three cases.

A mineral cannot always be determined by a single one of these properties, and for this reason they should be used in conjunction with one another.

The important minerals and groups of minerals to be considered in reference to building stone are quartz, feldspar, mica,

amphibole, pyroxene, chlorite, olivine, talc, calcite, dolomite, magnetite, hematite, limonite, and pyrite. The following is a short description of these minerals, giving the composition, physical characteristics and appearance of each.

QUARTZ.

The chemical composition of quartz is silicon dioxide ($Si O_2$) which is a combination of the two most abundant known elements, silicon and oxygen. It is one of the hardest of the common minerals, being seven in the scale of hardness. It will readily scratch glass and most of the other common minerals. It possesses no ready cleavage, having, as a rule a conchoidal fracture. As a rock-making constituent, quartz is generally colorless, but when found alone it is frequently brown, yellow, purple, milky white, or pink. When occurring alone or in crystal aggregates, the quartz individuals often have very perfect crystal faces, but as a rock-making constituent the individuals generally have round, oval, or irregular outlines.

Quartz is one of the most abundant minerals. The glistening sand which forms the bars in many of the larger rivers is mainly quartz. The white and yellow particles which are caught up by the wind and eddied here and there in small dunes over some of our farms, are mainly quartz. This loose sand is largely a result of the decomposition of sandstone, which is composed mainly of quartz. Quartzite, as the name implies, is composed essentially of quartz. Among the igneous rocks, such as granite, rhyolite, and gneiss, quartz is a prominent constituent. Rocks which do not contain more or less quartz are the exception rather than the rule.

Among all the common rock-forming minerals quartz is the most permanent. Hydrofluoric acid alone will dissolve it. It is very hard and resists, to a high degree, any attempt to break or crush it. As a result of weathering it is often broken into smaller particles, but it is decomposed and taken into solution only with exceeding difficulty.

FELDSPAR.

The feldspar group contains two series of minerals, under both of which are included several species and sub-species. Certain of the species differ in the elements which enter into their composition, while others differ merely in the percentage of such elements. The two series of minerals are known by the name of their most common member, as orthoclase and plagioclase. Orthoclase is composed of an admixture of potassium, aluminum, silicon, and oxygen, with occasionally a small percentage of sodium, $(K, Na)_2 Al_2 Si_6 O_{16}$ (Hintze). Plagioclase contains sodium, calcium, aluminum, silicon, and oxygen, with either one of the following or some intermediate formula: $Na_2Al_2Si_6O_{16}$,—$Ca_2Al_4 Si_4O_{16}$. The two series differ not only in chemical composition but also in their habit of crystallization. The former crystallizes in what is known as the monoclinic system, while the latter crystallizes in the triclinic system.

A few characteristics will suffice to distinguish them from other associated minerals. The color is generally either pink or white. The hardness is six in the scale, being surpassed, among the common minerals, only by quartz. They have two very pronounced cleavages at right angles to each other, in consequence of which they generally have smooth, glistening faces. Feldspar is not as widespread or abundant a constituent of building stones as quartz. It is found mainly in the igneous rocks, although it is often a subordinate constituent of sandstone. It is an essential constituent of granite, gneiss, porphyry, and many of the allied rocks. In fact, it is seldom absent from any of the igneous rocks.

Feldspar is a compound which is decomposed and taken into solution with less difficulty than quartz, and is seldom found in the ancient rocks in a completely unaltered condition. Its ready cleavage permits of a more easy passage of water in and through its entire mass, presenting favorable conditions for slow chemical changes. The molecules are in some manner slowly broken down, and we have formed from the feldspar, by a rear-

rangement and recombination of the elements, a variety of different products, among which may be mentioned kaolin, quartz, chlorite, mica, epidote, zoisite, and calcite. Decomposition of the feldspar takes place wherever it is exposed to the action of percolating water or to the weathering action of the atmosphere. In some manner these alterations, however slowly they act, must eventually affect the strength and durability of the rock of which the feldspar forms a part.

MICA.

As in the case of feldspar, there are several varieties of mica differing from one another either in the combination, or in the relative amounts of the elements which compose them. The two most important species are muscovite and biotite. Muscovite contains various proportions of the elements hydrogen, potassium, aluminum, silicon, and oxygen, while biotite differs mainly in containing, in addition to the above named elements, magnesium and iron. The hardness of muscovite is 2–2.5, while that of biotite is 2.5–3. Mica is distinguished from other associated minerals by its easy and close cleavage. It has the appearance of being composed of very many exceedingly thin, glossy sheets, piled one upon another. Each sheet or folio can be scaled off with the blade of a pen-knife, or often with the finger nail. Biotite is generally black or very dark brown, owing to the iron in its composition. Muscovite is ordinarily distinguished from biotite by its white or silvery white color. The dark color of some rocks is largely due to the abundance of biotite in their composition, while many of the gray granites owe their color partially to the presence of muscovite.

Biotite is very slowly altered to other compounds by exposure to the atmosphere. The resulting products of decomposition are iron oxide, quartz, chlorite, and a mixture of the carbonates. On the other hand, muscovite, under the same conditions, decomposes more slowly than biotite. The alteration of biotite takes place along the cleavage planes or between the laminæ, which hasten decomposition by furnishing a larger working surface to the agents of decomposition.

Mica is an essential constituent of granite, gneiss, and many other igneous rocks. It also occurs to a less extent in certain of the sedimentary rocks, of which micaceous sandstone is an example.

AMPHIBOLE.

The mineral species included under the general name of amphibole are composed mainly of magnesium, calcium, silicon, iron, manganese, and oxygen, with or without aluminum. The most common species are actinolite, in which aluminum is wanting, and hornblende in which aluminum is present. The hardness of these minerals is about that of apatite or feldspar, being from 5 to 6 in the scale of hardness. Actinolite, as often found in the igneous rocks, occurs in long needle-shaped crystals, while hornblende is columnar. The color of these varieties is usually green, brown, or black. Other varieties of amphibole are colorless to silver gray. The minerals of this group differ from those of the pyroxene group, to be next described, only in their mode of crystallization. For this reason it is often difficult to distinguish them from each other. The prismatic cleavage is the most useful distinguishing characteristic. In the amphiboles the angles of intersection are 124° 30′ and 55° 30′, while in the pyroxenes the angles are uniformly nearly 90°. The cleavage faces have a vitreous to pearly luster.

Amphibole is an essential constituent of many granites, but more especially of the basic igneous rocks. It is also an abundant constituent of many schists and altered sedimentaries. The alteration products of amphibole depend upon the species under consideration, but they consist mainly of talc, calcite, chlorite, epidote, and quartz. These minerals, in turn, may be still further decomposed, as in the case of chlorite, which breaks up into "a mixture of carbonates, clay, limonite, and quartz." (Rosenbusch.) Under ordinary conditions at the surface of the earth, actinolite is a more stable compound than common hornblende. It must be understood that all the changes referred to take place very slowly.

PYROXENE.

The composition of the mineral species included under the general name of pyroxene is nearly the same as that of the species included under the amphibole group. The individuals of this group are ordinarily composed of one or more of the elements magnesium, calcium, iron, manganese, sodium, and lithium, in combination with silicon and oxygen, with the addition in certain of the important species, of aluminum, as an essential constituent. The hardness varies from 5 to 6, but in some of the less common species reaches as high as 7. The color and luster of the cleavage faces are essentially the same as in the preceding amphibole group. As has been previously observed, it is difficult to distinguish the members of this group from those of the preceding. The only ready means is through a determination of the cleavage angles, or a knowledge of the crystal forms. The most important rock-forming member of this group is augite, which name is often used synonymously with pyroxene.

Pyroxene is mainly a constituent of igneous rocks, being an important constituent of many of the granites, gneisses, and especially of the more basic rocks.

Through the weathering processes pyroxene is slowly decomposed, altering into chlorite, calcite, and epidote. Under given conditions pyroxene weathers somewhat more rapidly than amphibole, and for this reason is considered a less stable compound.

CHLORITE.

This group of minerals, in which is included a number of species, is composed of various combinations and proportions of magnesium, iron, manganese, and aluminum, with hydrogen, silicon, and oxygen.

The hardness of the minerals of this group ranges from 2 to 2.7. The members of the chlorite group are characterized by their green color, which is common to silicates containing ferrous iron. In itself, chlorite is generally an alteration product of some other mineral. It occurs in fibers and folia in many of the old igneous rocks known as "greenstone," in which case it is

generally an alteration product of amphibole, pyroxene, feldspar, or mica. Chlorite alters to a mixture of carbonates, clay, limonite, and quartz.

OLIVINE.

The olivine group is now more correctly known as the chrysolite group. The different species differ somewhat in composition, being composed of varying proportions of magnesium, calcium, iron, and manganese, in combination with silicon and oxygen. The hardness ranges from 6 to 7. The predominant color is what is commonly known as olive green. The luster is vitreous. Olivine is a constituent, mainly, of the more basic igneous rocks, such as diabase and gabbro. It alters very extensively to chlorite, talc, and serpentine.

TALC.

Talc is composed of hydrogen, oxygen, iron, magnesium, aluminum, and silica, united in different proportions. It is usually foliated, but frequently massive or fibrous. Talc has a peculiar greasy feel which furnishes, as a rule, a ready means of distinguishing it from associated minerals. The color varies from apple green to white or silvery white. The luster is often pearly on cleavage faces. Talc is widely disseminated through the igneous and metamorphic rocks.

CALCITE.

Calcite is composed of the elements calcium, carbon, and oxygen. It is more accurately known as calcium carbonate, ($Ca\,C\,O_3$). The hardness is 3. Calcite is sometimes clear and transparent, but is more often white or cloudy. It sometimes contains impurities which impart a brown or pink color. It has a perfect cleavage in three directions, by means of which it breaks into small six-sided pieces, with inclined faces, called rhombohedrons.

Calcite is often mistaken by the inexperienced for quartz. The color of the two minerals is almost identical, but if one will bear in mind that the hardness of calcite is 3 and that of quartz

7, there can be little danger of confusion. Furthermore, calcite has the perfect cleavage, above mentioned, which is not present in quartz. Calcite is an essential constituent of all limestones and many sandstones. It is also a constituent of many of the igneous rocks, being an alteration product of other minerals. The only important alteration product of calcite is gypsum or the sulphate of calcium. According to Geikie, sulphate of calcium frequently forms as an outer crust on marble tombstones, due to the action of sulphuric acid. It is not known how general this product may be, but it appears very probable that the efflorescence observed on many limestones may be due to the formation of calcium sulphate.

DOLOMITE.

Dolomite is composed of calcium, magnesium, carbon, and oxygen, and has the formula: (Ca Mg) CO_3. Its hardness is from 3.5 to 4, which is slightly above that of calcite. It may be distinguished from calcite by this quality, but more easily by the fact that it does not dissolve in cold, dilute hydrochloric (muriatic) acid, while calcite does. Dolomite is found abundantly as a constituent of the dolomitic limestones. The main alteration is to the sulphate which is commonly found at or near the exposed surface of dolomitic limestone.

MAGNETITE.

Magnetite is commonly known as magnetic iron ore. It is composed of iron and oxygen and has the formula: Fe_3O_4. The hardness is 5.5 to 6.5.

Magnetite is one of the commonest constituents of the igneous and metamorphic rocks, and is most often present in small grains or crystals scarcely visible to the naked eye. When present in larger individuals it is easily recognized by its brilliant black luster and the property which it has of being readily attracted by the magnet. Magnetite is not only widely disseminated in grains, crystals, and irregular patches through the igneous and metamorphic rocks, but it also occurs in large beds, constituting a valuable iron ore. Magnetite alters slowly to

yellowish brown limonite "which impregnates the surrounding rock."

HEMATITE. (Red hematite.)

Hematite, or iron sesquioxide, is likewise composed of iron and oxygen, but the proportion of the two elements is different from that in the magnetite. The chemical composition of hematite is Fe_2O_3. It has a metallic luster. The streak is red. The color is generally steel gray to iron black but as a rock constituent it is often found in minute blood-red flakes. Besides occurring as a rock constituent, it is often discovered in massive beds, forming one of the most valuable iron ores. It often occurs as a cementing material in sandstone, binding together the individual grains, and with limonite is generally the cause of the brown and red color of the sedimentary, igneous, and metamorphic rocks. Hematite hydrates very slowly to limonite.

LIMONITE. (Brown hematite.)

The chemical composition of limonite is the same as that of hematite, with the exception that it contains water in addition to iron and oxygen, ($Fe_2O_3\ 1\frac{1}{2}\ H_2O$). It is found in all kinds of rocks—eruptive, sedimentary, and metamorphic. It results mainly from the decomposition of other minerals rich in iron. As a staining or coloring agent, it is probably more abundant than red hematite. It also occurs in large masses, and furnishes a valuable iron ore.

PYRITE.

The chemical composition of pyrite is iron and sulphur ($Fe\ S_2$). The hardness is 6 to 6.5. Common pyrite, or pyrite proper, is recognized by its cubical shape and bright yellow color. The less common form of iron sulphide, known as marcasite, has a much lighter, almost gray color, and is softer than common pyrite. The occurrence of iron sulphide in both forms is very wide spread, being found alike in eruptive, sedimentary, and metamorphic rocks. Both compounds decompose rather

readily, but pyrite proper is less affected by atmospheric conditions than marcasite. This is due to the fact that much of the iron in the marcasite exists in the ferrous state, while that in the pyrite is more largely in a ferric condition.[1] Under the same conditions, the ferric compounds are much more stable than the ferrous, and hence the greater readiness with which the marcasite decomposes. The decomposition products of the two minerals also differ to some degree. The decomposition of pyrite results, as a rule, in the formation of limonite and free sulphur, while that of marcasite results in the formation of ferrous sulphate, although when under water limonite is also largely formed.

ROCKS.

A rock is ordinarily defined as a mineral aggregate. It consists of individuals of one or more mineral species in which the particles are either cemented together or otherwise consolidated. Rocks are ordinarily classified, on the basis of their origin, into igneous, aqueous (or sedimentary), and metamorphic. This basis of classification is not altogether satisfactory to the student of geology, but is convenient for the purposes of this volume.

The important rocks from an economic standpoint, which are found in this state, may be classified as follows:

IGNEOUS.
- Granite.
- Rhyolite. (Quartz porphyry.)
- Greenstone.

SEDIMENTARY.
- Sandstone.
- Limestone.
- Dolomite.

METAMORPHIC.
- Quartzite.
- Gneiss.

It must be understood that this classification is very general, and that between the few kinds of rocks mentioned, many differ-

[1] Mr. A. P. Brown, Proc. Amer. Phil. Soc., Vol. XXXIII., 1894, p. 225.

ent varieties have been distinguished and named. There exist all gradations between the rocks of the sedimentary series as well as between the rocks of the igneous series. Each rock type passes by insensible gradations into the adjacent type of the series to which it belongs. Likewise, there are all gradations between the igneous, aqueous, and metamorphic rocks.

IGNEOUS ROCKS.

Igneous rocks, as the name implies, are those rocks which have had their origin in the cooling and consolidation of molten material. Provided we accept the hypothesis that the earth was at one time a molten mass, which has subsequently cooled, igneous rocks may be either a result of the downward cooling of the earth's crust, or a result of the consolidation of molten material which has been pushed up from below into or through the already cooled crust.

These rocks exhibit many different characteristics. The different conditions under which the molten material solidifies and differences in the chemical composition of the original magma are the main, controlling factors in producing differences in the mineralogical composition and the size and arrangement of the grains. Upon these differences in mineralogical composition and size and arrangement of the individual grains, several different classifications of igneous rocks have arisen. None of these classifications has been generally accepted as satisfactory. It would be entirely out of place to describe all of the many different kinds of rock included in any one of these classifications. It is thought that only a description of the more important kinds found in the state of Wisconsin, which are now used for economic purposes, is necessary. These are granite, rhyolite, and greenstone.

Granite.

Granite is supposed to form deep below the surface of the earth, under peculiar conditions of heat and pressure, whereby the elements of the molten magma are allowed to enter into various combinations, forming minerals having definite char-

acteristics. The rock thus formed is completely crystalline, and composed of the essential constituents quartz, orthoclase feldspar, and plagioclase feldspar, with one or more minerals from the mica, pyroxene, or amphibole series. Magnetite, pyrite, zircon, apatite, and a number of less important microscopic minerals are present as accessory constituents. The minerals, as a rule, have irregular outlines and interlock in a very intricate manner, each of the individuals having very much the appearance of being irregularly dove-tailed into those adjacent. This interlocking character of the minerals accounts for the fact that, as a rule, an individual can only be separated from the mass of the rock by severing it at some part. This characteristic of igneous rocks also accounts, in part, for their strength and the difficulty which stone cutters experience in working them.

In certain of the granites the essential mineral constituents are very small, being distinguishable only by the aid of a lens. Such a granite is generally designated as fine grained. In others the essential constituents are often as much as a quarter or even a half an inch in diameter. These are spoken of as being either coarse or very coarse grained. Between the two extremes there are all degrees of coarseness (or fineness). Frequently a granite is found in which certain of the feldspar individuals are very large and stand out boldly in a fine grained groundmass. Such a rock is called a porphyritic granite.

Granites are discriminated from one another by the predominant ferro-magnesium mineral among their constituents, and are known as biotite-granite, muscovite-granite, hornblende-granite, augite-granite, etc.

The color of granite differs greatly in different localities. The color depends, not alone upon the color of the individual minerals composing the rock, but also upon the size and distribution of the constituents. With respect to color, granites may be classified as red and gray. Whether a granite belongs to the first or second class will depend upon the red or white color of the feldspar. Many granites contain both red and white feldspar, but so long as the red variety is sufficiently abundant to impart a reddish tone to the rock, it is called a red granite.

The most brilliant red granites have a preponderance of medium-sized red feldspar individuals. As the individuals become finer grained and biotite, amphibole, or pyroxene become more abundant, the color is subdued and we have a dull red granite.

The gray granites are dark or light colored, depending upon the size of the individual minerals and the amount and kind of the ferro-magnesian minerals present. The lightest colored granite has a preponderance of white feldspar and contains muscovite as the main ferro-magnesian mineral. The darker gray granites contain less feldspar and a greater abundance of biotite, hornblende, or pyroxene. Occasionally one finds a granite which has a peculiar iridescent hue, which is due to the presence of one of the plagioclase feldspars, usually labradorite.

Granite is generally massive, but occasionally one finds a quarry in which the rock splits in one direction much more readily than in others. This direction is known by quarry-men as the rift. When it becomes very pronounced and wavy the granite is known as a gneiss, and should be classified under the metamorphic series.

Granite is fresh or altered, depending upon the state of preservation of the mineral constituents. The more common alterations to which the various rock forming minerals are subject have been mentioned above. One can readily see that the alteration and decomposition of the individual minerals would, in time, result in a breaking down or crumbling of the rock itself. The degree of alteration and the alteration products as they affect the durability of a rock will be considered later.

Rhyolite.

The rocks which have been placed under this subdivision have essentially the same chemical composition as granite. They differ mainly in texture and mineralogical composition, occasioned by the entirely different conditions under which they have been formed. In contra-distinction to the granites, which are formed deep below the surface, these rocks are formed at or near the surface of the earth.

Porphyritic rhyolite, commonly known as quartz porphyry, is the only variety of this kind of rock which we have occasion to consider. In this rock, quartz and feldspar are the first minerals to crystallize out from the magma, and constitute the porphyritic elements in the rock. Sometimes feldspar alone is present, and again both quartz and feldspar are found among the porphyritic individuals. The remainder of the magma is supposed to have cooled so rapidly as to permit of only fine grained or partial crystallization. The rock, as a rule, has a dark, dense background, through which are disseminated numerous large, lustrous crystals of feldspar or quartz, or frequently both. These porphyritic constituents of rhyolite generally differ from those of granite in having well defined crystal outlines. The matrix of porphyritic rhyolite, as it now occurs, is often composed of a dense mass of microscopic crystals of quartz and feldspar. In other instances the matrix may be entirely or in part amorphous.

The color of the Wisconsin rhyolites used for building stone ranges from yellowish brown to black. A very pleasing effect is sometimes produced by a black groundmass through which are promiscuously scattered porphyritic crystals of pink and white feldspar and clear, translucent individuals of quartz. Rhyolite is an exceedingly hard and brittle rock, often breaking with a conchoidal or splintery fracture. The rock very often exhibits a tendency to split more readily in one direction than in others. Frequently there are two directions of easy parting, one being better developed than the other. The direction of easiest parting is known by quarrymen as the "rift;" the direction of next easiest parting has been designated the "run." The third direction is known as the "head." The rift may be the result of flowage planes developed before the rock was completely solidified; it may have been occasioned by alterations since the formation of the rock; or it may be a result of both. The rift and run assist very materially in quarrying the rock, but the rift is often a serious obstacle to satisfactory polishing. The rift side is the direction of the longest axis of the flattened minerals, and the exceptional closeness of the parting planes is a cause for the difficulty experienced in polishing the rock with the rift.

Greenstone.

In the nomenclature of igneous rocks the name "greenstone" has no definite significance, having been applied to almost any rock which has a green color. The main kinds of greenstone in Wisconsin which might be used as building material are known as diabase, gabbro, and basalt. These rocks have, as their main constituents, plagioclase feldspar, amphibole, mica, and pyroxene. All of the three last may or may not be present. To these essential constituents may be added from ten to twelve accessory minerals, some of which are present in each kind of rock.

Diabase is one of the most abundant and widespread igneous rocks in Wisconsin, being found in huge bosses, dikes, and sills. It is formed originally within the crust of the earth, and is distinguished from the other members of the family by the texture known as ophitic. This texture may be either macroscopic or microscopic. The rock is usually fine to medium grained, and seldom has a porphyritic texture. It is generally compact and thoroughly homogeneous. The color of diabase is decidedly somber, being dark green and sometimes almost black.

The gabbro member of the family is distinguished from diabase by its granolithic texture, which is always microscopic. The mineralogical composition, color, and occurrence are quite analogous to that of diabase.

Basalt is commonly a volcanic rock. It is sometimes completely crystalline and at other times partly glassy. The texture at times approaches microgranolithic. The mineralogical composition and color correspond quite closely with the two previously described members.

It will be noted that the constituents of the greenstones are among the more readily decomposed and disintegrated minerals. For this reason, and on account of the dark, somber color of the rock, they are not generally sought after as building stones.

AQUEOUS OR SEDIMENTARY ROCKS.

The sedimentary rocks have their origin in chemical or organic precipitation and mechanical deposition from water. If it were possible to trace back the history of the material com-

posing the sedimentary rocks to its original source, one would find that a large part had its origin in the igneous rocks of long ago. The rivers are constantly transporting millions upon millions of tons of finely comminuted material from the land into the sea. Millions of tons are also being carried in solution. The waves, beating upon the shore, are steadily wearing it back by breaking down the rocks along the coast. The shore currents, waves, and tides assort the material which is worn from the coast and that which is brought into the ocean by the rivers, depositing it over the bed of the ocean near the land. The coarsest material is dropped nearest the shore, while the finer material is carried into deeper water. The ocean is inhabited by myriads of animals and plants that are continually extracting calcium carbonate and silica from the water, to build their shells and skeletons. As these creatures die their shells are added to the accumulations at the bottom of the ocean, and in many places they become so abundant that they form a large part of the deposit.

Beside calcium carbonate and silica, which are the substances mainly used in building the shells of marine animals, the water carries in solution many other soluble mineral substances. These are also often precipitated to the bottom of the ocean, mingling themselves with the mechanical sediments and organic remains. Through these various agencies four principal kinds of sediments are formed—conglomerate, sandstone, shale, and limestone or dolomite. These deposits are not sharply separated from one another, but between them every possible gradation may be found.

Conglomerate.

Close to the shore line the coarser pebbles and boulders, which have been worn away from the cliffs of the adjacent coast, are laid down. These pebbles are generally well rounded and in the spaces between the individuals finer material settles until the whole becomes a compact, solid mass. This interstitial material is known as the matrix, and is generally either sand or clay. When such a deposit has been buried underneath many thousand feet of other sediments, it becomes consolidated and

forms rock conglomerate. After many centuries, through elevation and subsequent wasting away of the land, the conglomerate thus formed may emerge again at the surface as a part of the continental land mass.

Where the pebbles are comparatively uniform in size conglomerate is sometimes used for economic purposes. But as a rule the decided difference in texture and hardness between the different pebbles and between the pebbles and the matrix, is a fatal objection to its use as a building stone. It sometimes serves as a beautiful stone for inside ornamental work, where it is protected from the destructive action of the weather. There are no conglomerates in this state of recognized economic value, and we shall therefore pass them without further discussion.

Sandstone.

The next distinct deposit beyond the conglomerate belt and in deeper water is that composed of small particles of sand. After the sand is deeply buried beneath later sediments and the interstices become filled or partly filled with materials deposited from percolating waters, the incoherent sand is transformed into a rock known as sandstone.

The composition of sandstone varies quite largely, but in all cases the preponderant original constituent is round to subangular grains of quartz. Feldspar or calcite may constitute a considerable portion of the rock, in which case it is called either a feldspathic or calcareous sandstone. Clay may be so intermingled with the quartz grains as to give the rock the name argillaceous sandstone. Mica may also be abundant, and the rock is then called a micaceous sandstone.

The original grains which compose the rock generally have roundish outlines, owing to their having been water-worn. The individuals, therefore, do not interlock as in the case of the igneous rocks. When first deposited small spaces exist between the grains, but due to consolidation from superincumbent pressure, these spaces may be reduced in size, and through cementation they are either partly or wholly filled by material from extraneous sources.

The kind of cementing material which binds together the grains will depend largely upon the mineral matter carried in solution by the water, which has percolated through the rocks, although the mineral particles composing the rock may contribute largely to the force which occasions precipitation of the cementing material. The more important cementing materials are calcium carbonate, iron oxide, and silica.

It is evident that the hardness of a rock depends upon the state of aggregation, as well as upon the hardness of the individuals composing the rock. The hardness of quartz is 7, but this is not the hardness of a rock composed entirely of an aggregate of quartz grains. The hardness of the rock will depend more upon the manner in which the grains are cemented, or united, and the character of the cementing material. The efficiency of the cement will depend not only upon its inherent characteristics, but also upon the affinity which exists between the grains and the cement. The hardest and most durable cement is silica. A sandstone in which the individuals are completely cemented with silica is one of the hardest and most durable rocks. Sandstone in which the cementing material is calcium carbonate is softer and less durable than the former. Calcite is one of the softest of the important minerals of building stone and breaks very readily into small pieces, due to its cleavage. It is also quite readily dissolved in carbonated waters. A sandstone in which the individuals are cemented with iron oxide is less strong than one cemented with either silica or calcite. As a rule, iron oxide is the least important of the three cements. Writers are constantly classifying iron oxide as a more durable cement than calcite, probably drawing their conclusions from the durability of the brown sandstone. But the most durable brown sandstone, such as occurs in Wisconsin, is mainly cemented with silica and not iron oxide. The value of the iron oxide is mainly in imparting to the rock the beautiful shades of red and brown, for which much of the Wisconsin sandstone is noted. Thus it happens that errors have frequently been made concerning the relative importance of silica, calcite, and iron oxide as cementing materials.

Any estimate of the hardness or durability of a rock should take into consideration the conditions of cementation. In comparing the hardness and durability of sandstone, the relative amount of cementing material, the size of the grains, and the completeness with which the cement has filled the interstices, as well as the kind of cement and mineral constituents, should be taken into consideration.

Alterations of sandstone are mainly the result of additions or subtractions of mineral matter, usually silica. Quartz, as has been previously stated, does not alter, although small amounts may be taken into solution and carried away by percolating water. The cementing materials and the subordinate constituents, such as feldspar, mica, calcite, and iron oxide (or sulphide), are alone subject to alteration in the sense of decomposition. Feldspar and mica break down into their various alteration products, and calcite is often dissolved and reprecipitated as the sulphate. Ordinarily iron oxide, in the form of hematite, is reasonably stable; in the form of the carbonate or sulphide, it is readily decomposed and becomes a source of unsightly discoloration.

Shale.

In deeper water but mainly in the shallows of the ocean, beyond the sandstone belt, still finer sediments are deposited in the form of clay. These deposits, after passing through the ordinary process of consolidation, are also transformed into a rock, which is known as shale. These rocks have no economic importance in Wisconsin and will not be further considered.

Limestone and Dolomite.

Beyond the clay there occurs a deposit of calcium carbonate or calcium magnesium carbonate ($CaCO_3$ or $CaMgCO_3$). This deposit is composed largely of the shells of marine animals in conjunction with calcium carbonate resulting from chemical precipitation. This deposit, as in the case of those previously described, is consolidated and transformed into rock through the pressure of superincumbent deposits and the addition of

cementing material from percolating water. This rock, like the former, may be brought to the surface as a part of the land and is known either as limestone or dolomite, depending upon the percentage of magnesium carbonate present.

The method of formation of the dolomitic limestone has been the subject of a great deal of discussion. Some authorities attribute it entirely to secondary processes after the limestone is deposited, while others assert that it can only be accounted for by contemporaneous chemical precipitation and the extraction of (CaMg) CO_3 by living organisms. The probability is that both original and secondary processes have contributed to its formation. In one place chemical precipitation may have been the chief agent, while in another it may have been the result of secondary processes. In other places both agencies may have been equally operative.

The chemical composition of pure limestone is calcium carbonate, a combination of the elements calcium, carbon, and oxygen. It is seldom that limestone occurs in the pure state among the rock formations of Wisconsin. Magnesium, silica, clay, iron oxide, and bitumen are all of common occurrence. By far the most abundant of these accessory constituents is magnesium in the form of dolomite (Ca Mg) Co_3.

Owing to the presence of magnesium in large quantities in certain of the limestones, authors have been accustomed to apply the name dolomite to limestone, which contains a certain percentage of Mg CO_3, ranging from 18 per cent. to 40 per cent., depending upon the writer. The term dolomite has such a varied meaning and has been used so loosely by different authors, that it would avoid confusion if some definite usage for it was established in the nomenclature of rocks. For scientific as well as practical purposes, it would be best, as far as possible, to distinguish limestone and dolomite as different kinds of rock. If the rock is essentially pure calcium carbonate, it should be called a limestone. If the rock is essentially calcium-magnesium carbonate, it should be termed a dolomite. If the dolomite becomes important, but not predominant, the limestone should be known as dolomitic or magnesian limestone. If the

percentage of calcium carbonate is less than that of the calcium magnesium carbonate the rock should be called a calcareous dolomite.

There are all gradations between the rocks in which the chemical composition is pure limestone, calcium carbonate, and those in which the chemical composition is pure dolomite. The stone may be a limestone, a dolomitic limestone, a calcareous dolomite, or a dolomite. Either may be qualified by affixing the name of the most abundant subordinate constituent. If this subordinate constituent chances to be clay, the rock would be an argillaceous limestone or dolomite; if iron, a ferruginous limestone or dolomite; if bitumen, a bituminous limestone or dolomite. Silica often occurs either as original grains of quartz or as a product of infiltration. It may be almost equal in importance to that of calcium carbonate and in such case the rock might with equal propriety be called an arenaceous limestone or a calcareous sandstone. Iron is frequently a subordinate constituent, either as the carbonate, oxide, or sulphide. If present in any considerable quantity the rock is known as a ferruginous limestone. Iron is a cause of the discoloration of many of the limestones, after being placed in the walls of the buildings. Oxide, in the ferric form, is not liable to cause discoloration after the stone is placed in the wall, but when the iron is present as the carbonate of sulphide, it may, in the case of limestone, not only be a source of discoloration, but also injure the texture of the rock. The sulphide of iron, as previously mentioned under the description of mineral species, is found in the form of pyrite and marcasite. Hopkins, in his report on the marbles of Arkansas (p. 60) says: "The sulphide of iron is more liable to decomposition when it is in the form of marcasite than in the form of yellow pyrite, and is less destructive in dry places than in moist ones, as in the presence of moisture it not only forms the oxide known as iron rust, but it at the same time produces sulphurous and sulphuric acids which act on the lime, changing it to sulphate of lime or gypsum. Often the only effect of iron, if present in very small quantities, is to mellow the stone, producing a yellow tint with age."

Clay may occur in the limestone either as thin laminæ between the layers, as segregations, or disseminated in fine particles throughout the stone. An admixture of clay has a tendency to soften the limestone, thereby making it less durable. If present in thin laminæ or in pockets it will soon be noticeable by the greater rapidity with which it weathers. The surface will weather unevenly and soon become ragged and pitted.

Bitumen, either as petroleum or carbonaceous matter, is often an accessory constituent and imparts to the rock a black color and a fetid odor. The injurious effect of bitumen depends largely upon the amount present. It is objectionable, in any considerable quantity, on account of its odor and the discoloration which it occasions. Frequently limestone formations are reservoirs of great mineral wealth. Lead, zinc, copper, and mineral fuels are found in limestone formations. These minerals sometimes furnish qualitative names to the limestone, such as the "Galena" limestone.

Abysmal Deposits.

In the abysmal parts of the ocean, various deposits of ooze are now being formed, but it is thought that these have never contributed to the formation of the rocks of the continent.

METAMORPHIC ROCKS.

The metamorphic rocks are modified equivalents of the rocks of both the igneous and sedimentary series, which have been profoundly altered through dynamic and other agencies since they were first formed. Every rock in the igneous and aqueous series has its equivalent in the metamorphic series. Among these rocks may be mentioned gneiss, which may be an alteration product of either igneous and aqueous rocks, quartzite, which results from the induration of sandstone, and marble which is the metamorphosed equivalent of limestone.

The metamorphic rocks used as building stone in Wisconsin are mainly gneiss and quartzite. Certain of the limestones and dolomites approach very close to marble, but they have not been classified separately in this report. The gneiss and

quartzite have both been used to a limited extent for ornamental and constructional purposes, but the abundance of much more suitable materials among the unmetamorphosed rocks has retarded their development.

Quartzite.

When sandstone has been subjected to metamorphic processes, through many years, it is transformed into either a quartzite or a quartz schist. Quartz schist results from alteration combined with mechanical deformation, by which a cleavage or schistosity is developed. Quartzite is composed almost entirely of quartz, and differs from quartz schist simply in the absence of the laminated or schistose structure. In these rocks the grains of sand have largely lost their original, roundish shape, and now interlock in an intricate manner, much after the fashion of the grains of an igneous rock. Quartzite is composed essentially of quartz, and the cementing material is silica. Iron oxide is often present, imparting to the rock a red or brown color. Frequently other very subordinate constituents are associated with the quartz. The color varies through white, gray, red, blue, or brown.

Quartzite is an exceedingly refractory stone, and is worked only with the greatest difficulty. This quality, combined with its always numerous joints, almost wholly prevents its economic use, except for road construction.

Gneiss.

Gneiss is the general term applied to a series of schistose rocks having the constituents of granite. The rock may originally have been either igneous or aqueous. In some of the gneisses, the metamorphic process has only progressed far enough to produce a decided lamination, without obliterating evidences of the origin of the rock. In others all traces of the original rock have been removed.

Wisconsin possesses an abundance of gneissic rocks of all kinds, but owing to the great abundance of non-foliated rocks,

they are seldom quarried. Nevertheless, when polished they are often very pretty, and are more durable than many of the rocks ordinarily used.

ROCK STRUCTURES.

ORIGINAL STRUCTURES.

The original structures in sedimentary rocks are those which are produced through changing conditions of sedimentation or alternation of sediments. Through the alternation of sediments, there is formed a structure which I propose to call stratification. Originally the sedimentary rocks possess no actual planes of parting, but merely the stratification planes, which are planes along which the rock has a natural capacity to part most readily. The more abrupt the change in sediments, the greater will be the capacity for the rock to part along the sedimentary planes.

The igneous rocks formed below the surface of the earth are originally massive and homogeneous, and without original parting planes. Igneous rocks which have solidified at or near the surface often have developed an original flowage structure, which resembles, in some respects, the stratification planes of the sedimentary rocks and has frequently been mistaken for them. Such rocks have a capacity to part most readily along the flowage planes.

SECONDARY STRUCTURES.

One ordinarily thinks of the rock envelope at the surface of the earth as being one continuous, unbroken mass of rock. But when closely examined it is found at the surface to be composed of a mass of various sized, polygonal blocks, to all appearances perfectly fitted to each other. These polygonal blocks have a wide range in size. Often, they do not exceed several inches in cross-section, while occasionally they are fifty or even several hundred feet in each of the three dimensions. Blocks of all intermediate sizes may be found. It is known that the parting planes which bound these polygonal blocks are not original, but

that they have been produced since the consolidation of the rock. The most important of these parting planes are known as joints. Joints develop in the sedimentary and igneous rocks as the result of stresses, requiring a readjustment of the earth's crust in conformity with new conditions. Relief generally takes place where there is least resistance. In the sedimentary rocks the planes of sedimentation are the planes of weakness, and along these planes where originally there existed merely a capacity to part, actual parting takes place. These planes might consistently be called joints but I propose to call them *bedding,* in distinction from those that are normal or inclined to the plans of stratification. Other parting planes besides these may be developed in two or more directions, normal or inclined to bedding. Such fractures are known as joints, although ordinarily spoken of by quarrymen as vertical or inclined seams. Joints, normal or inclined to bedding, generally occur in sets almost at right angles to each other. They are ordinarily classified as "dip" joints and "strike" joints, depending upon whether they correspond in direction with that of the strike or dip of the rocks. A better classification would be that of tension joints and compression joints as proposed by C. R. Van Hise.[1] The first classification is unsatisfactory, in so much as it does not provide for the possible cases, and is often misleading. The latter classification is based on the origin of the joints, and is decidedly more satisfactory. Yet the classification is not of sufficient importance to quarrymen to warrant giving it serious attention.

Joints are known by quarrymen as "major" and "minor," depending upon how well they are developed, and for quarrying purposes this appears to be the most practical classification. The major joints are those seams which continue for a considerable depth and for long distances. The minor joints are those seams which originate and die out within short distances, often within the same quarry. The least of the minor joints are often known as "dry" or "incipient" joints. Often the larger

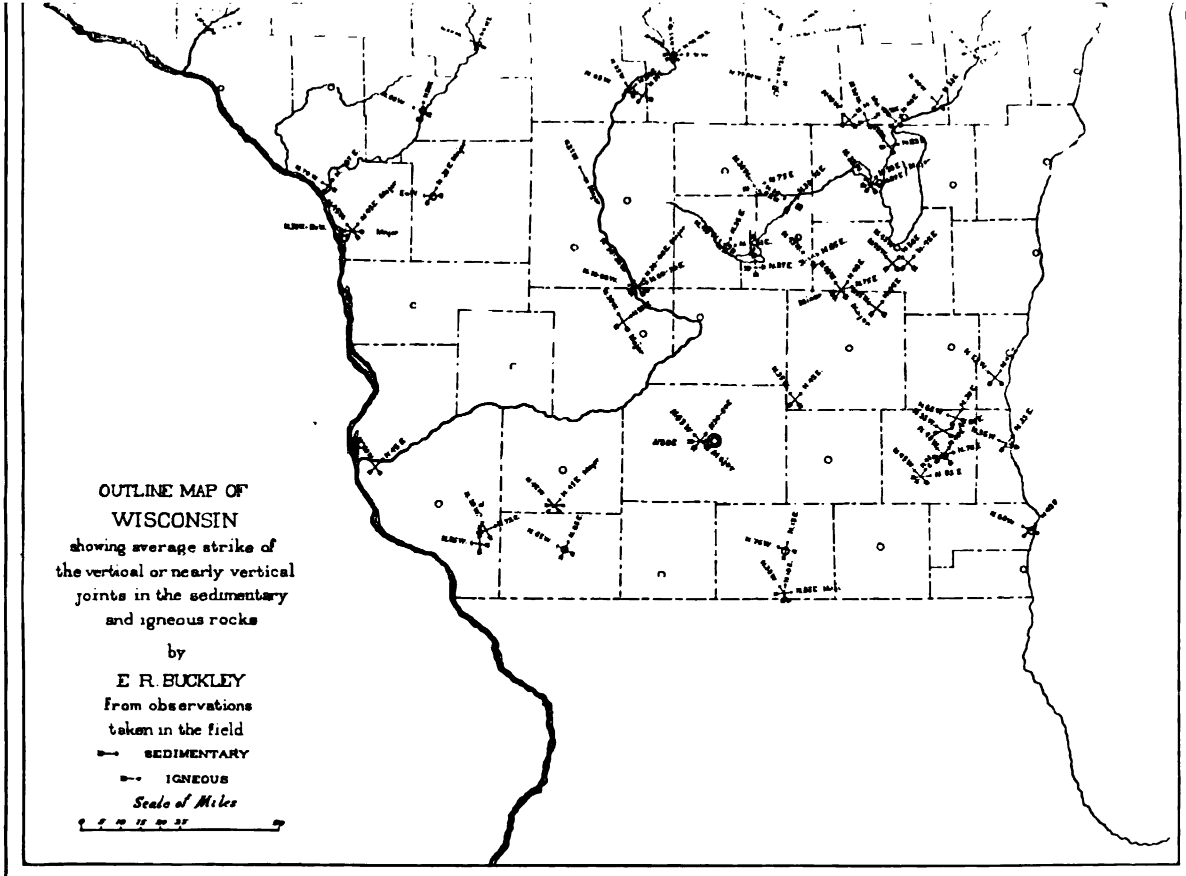
[1] Principles of North American pre-Cambrian Geology, by C. R. Van Hise: 16th Ann. Rep't, U. S. Geol. Survey, 1896, pp. 668–672.

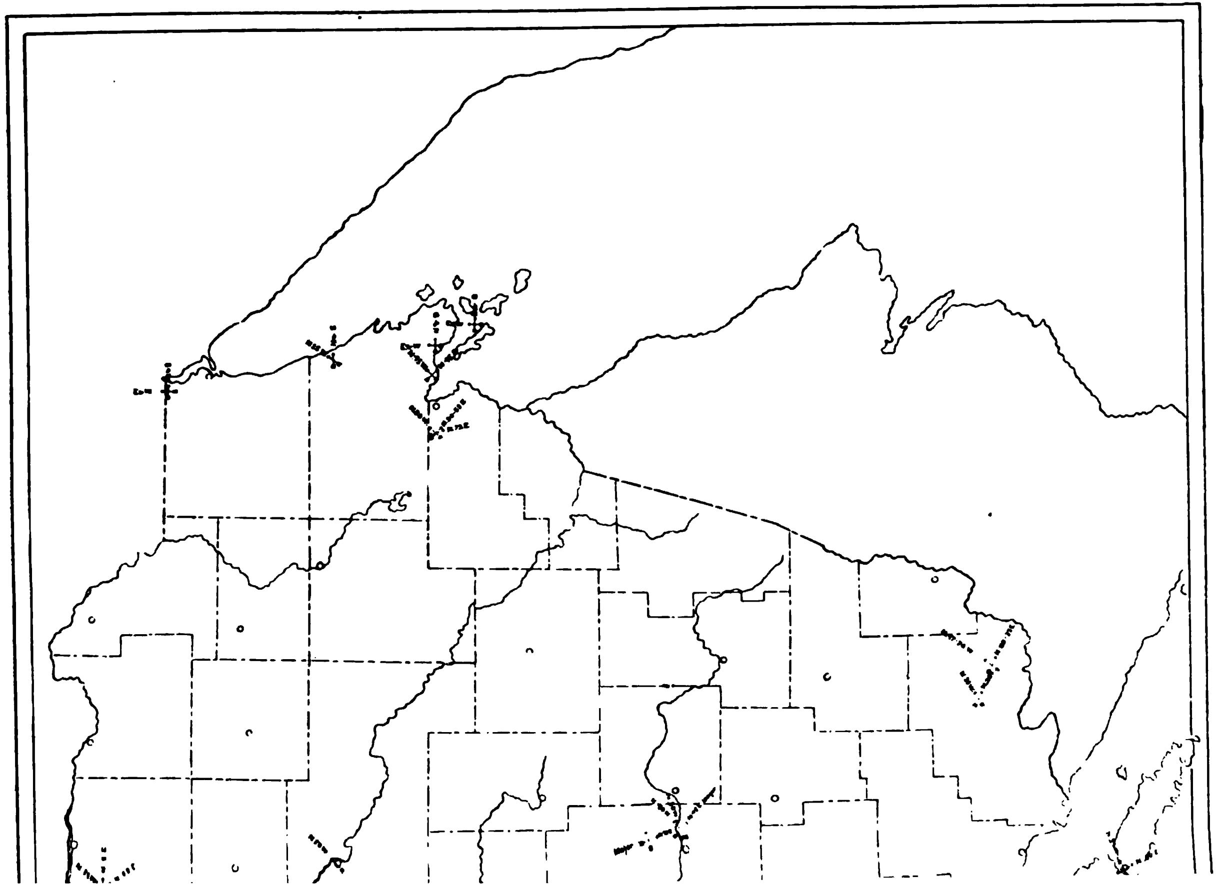
joints near the surface, have developed into narrow V-shaped trenches, sometimes 20 feet in depth. These are often filled with mud and clay, and are known by the quarrymen as "mud seams."

The advantages and disadvantages of these natural seams are well known to the quarrymen. The parting planes may be so distributed as to furnish dimension blocks of the most convenient size, or they may be so few in number as to make the expense of quarrying too great for economical working. Or again, they may be so abundant that the rock masses are fragments too small for dimensional purposes. Rock which is thus badly broken up may be most economically handled for road purposes. Where the stone is desired for heavy constructional work, the presence of numerous jointing planes is a source of great annoyance and expense to the quarrymen. In quarries where the jointing is uncertain, it is occasionally necessary to work over a large section of the quarry before finding blocks of the required dimensions.

Several hundred observations were made on the jointing of the rocks as it occurs in the different quarries throughout the state. These observations included a determination of the strike and dip of each set of joints, and a record of the most prominent sets. The results are embodied in the map, Pl. XLIX.

The jointing in the sedimentary rocks is quite different from that in the igneous rocks, being much more complex, as a rule, in the latter than in the former. In the sedimentary rocks bedding always occurs, and the jointing is mainly vertical, dipping only a few degrees in either direction. As a rule, the sets of joints occur in pairs striking nearly at right angles to each other. In most places two pairs of sets can be distinguished, each set striking at an angle of about 90° from the two adjacent sets. Two of the four sets are often equally well developed, while the third and fourth sets may or may not be equally well developed. The two sets that are best developed in one part of an area may be superseded in another part by the other two sets. The joints are often very abundant in one part of a quarry and sparse in another. Curved joints occur in the formations


OUTLINE MAP OF
WISCONSIN
showing average strike of
the vertical or nearly vertical
joints in the sedimentary
and igneous rocks
by
E. R. BUCKLEY
From observations
taken in the field
SEDIMENTARY
IGNEOUS
Scale of Miles



through the eastern part of the state, and occasionally faulting has occurred.

As will be seen in the accompanying map, the joints of the sedimentary rocks strike in four main directions. The prevailing general direction of the joints is NE. and SW. The other directions are NW. and SE., E. and W., and N. and S.

The joints in the igneous rocks are more numerous than in the sedimentary, owing to the greater length of time through which they have been subjected to dynamic action. The joints are partly vertical, but many of them are inclined or even approximately horizontal. The observations are recorded on the map, Pl. XLIX., along with those of the sedimentary rocks.

There may also be produced in rocks another structure parallel, inclined, or normal to stratification, known as cleavage. Cleavage is a capacity which a rock may possess to split readily into thin laminæ or folia. It is somewhat homologous to stratification, but is distinguished by being a secondary and not an original structure. The parting along cleavage planes is sometimes smooth, and at other times wavy. The former is known as slatiness and the latter as schistosity. Prof. Van Hise[1] has also made a distinction between fissility and cleavage. He defines cleavage "as a capacity present in some rocks to break in certain directions more easily than in others." Fissility is "defined as a structure in some rocks, by virtue of which they are already separated into parallel laminæ in a state of nature."

Thus in the sedimentary rocks one may recognize stratification, bedding, jointing, schistosity, fissility, and cleavage. In this report no attempt has been made to distinguish cleavage from fissility, although the author appreciates the necessity of such a division for scientific accuracy.

The rocks are sometimes variously folded and plicated, and the strata bent into domes and basins. These structures are observed mainly in mountanious regions and are not characteristic of the unaltered sedimentary rocks.

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[1] Principles of North American Pre-Cambrian Geology, by C. R. Van Hise: 16th Ann. Rep't, U. S. Geol. Survey, 1896, p. 623.

The igneous rocks exhibit analogous structures to those of the sedimentary rocks. Horizontal or nearly horizontal bedding is often found, either along the flowage planes of surface lavas, or in the originally structureless deep-seated rocks. Joints are developed in directions inclined or normal to bedding, as in the sedimentary rocks. In mountainous regions the rocks are often folded and plicated in a complicated manner, while fissility, cleavage, and schistosity, which generally accompany folding, are also usually developed. Slatiness and schistosity are especially characteristic of the oldest rocks, known as the Pre-Cambrian gneiss, and often occur over extensive areas.

In certain of the igneous rocks there has developed, either originally or secondarily, a differential parting capacity in three directions. This is exhibited mainly in certain of the rhyolites, in which the large porphyritic individuals have been elongated and flattened in a common direction. The plane of flattening is the direction of easiest parting, and is known as the "rift." The plane normal to this, and extending in the direction of elongation is designated the "run." The third plane, normal to the other two, is known as the "head." These structures do not commonly occur together in the same stone, although they are characteristic of the rhyolite from several of the important quarries in Wisconsin.

In general, it should be noted that the igneous rocks have structures which are in many respects analogous to those of the sedimentary rocks. It is important that one who is working in a quarry should be familiar with all the above structures, as it will often greatly facilitate the work of extracting the stone.

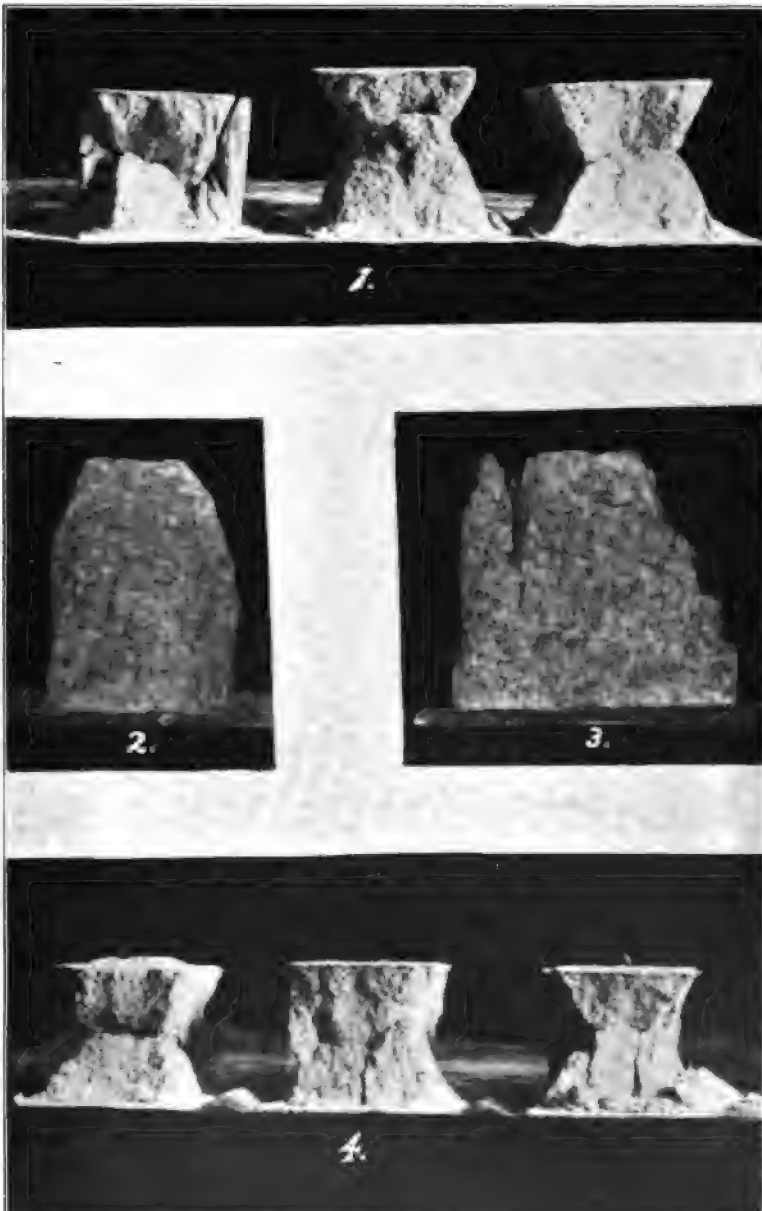
PLATE L.

PLATE L.—RESULTS OF CRUSHING SANDSTONE AND GRANITE.

FIGS. 1, 2, and 3.—Samples of brown sandstone in which the pyramidal forms are well developed.

FIGS. 4 and 5.—Samples of granite. Only the upper wedge or pyramid was developed in each cube. Fig. 2 approaches the conical form, which ordinarily results from crushing granite. (See Pl. LI.) Fig. 3 is the typical wedge-shaped form, which often results from crushing granite of medium strength.

FIGS. 6, 7, and 8.—Samples of brown sandstone in which the pyramidal structure is well developed. These are typical results obtained from crushing sandstone of ordinary strength. It should be observed that the samples which have a low or medium crushing strength are the only ones in which two equally well developed pyramids occur.



Results of crushing sandstone and granite cubes.

PLATE LI.

PLATE LI.—Results of Crushing Granite.

Figs. 1, 2, and 3.—These samples illustrate the different forms developed in crushing granite cubes. The one on the left is a typical cone. The one on the right has a tendency toward the wedge-shaped form, while the one in the middle is a typical wedge form. The upper part of this wedge is a sharp ridge from one end to the other.

Figs. 4, 5, and 6.—These three figures have their apices pointing toward the observer. They are all well shaped cones, in which there has been especially well developed the concentric structure referred to in the text.

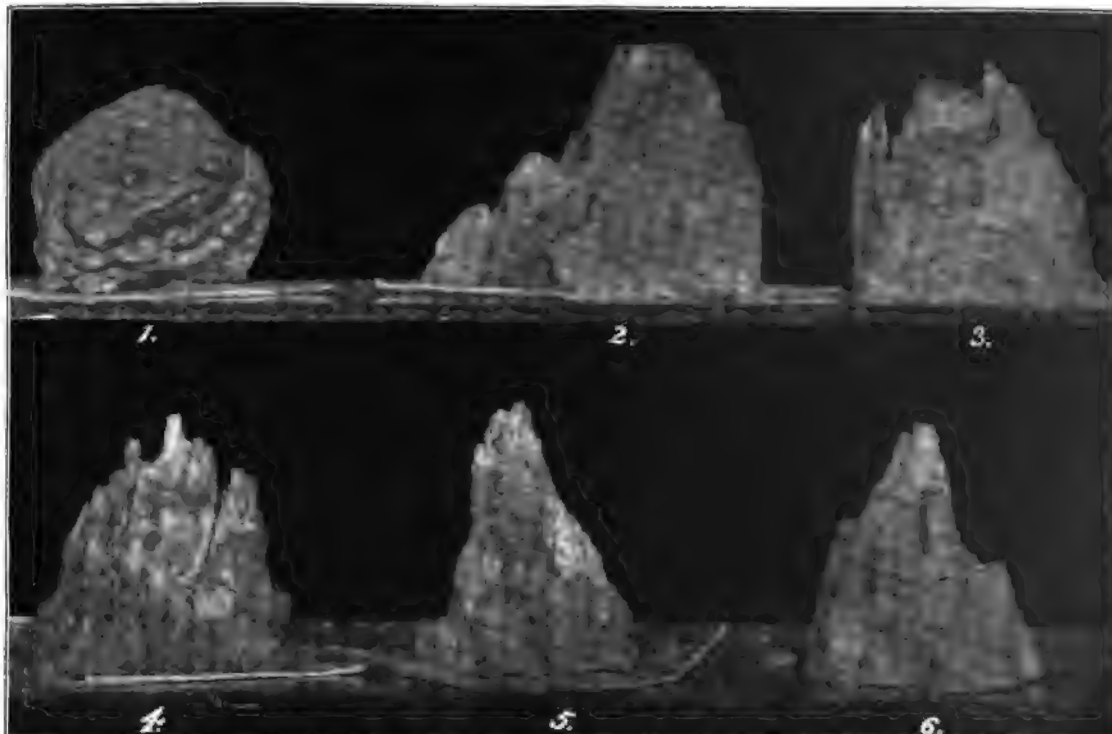
Results of crushing granite cubes.

PLATE LII.

PLATE LII.—Results of Crushing Limestone.

These samples show some of the ordinary results of crushing limestone of moderate strength. It will be noted that, in the limestone, there is a tendency to develop steeper cones, than in the granite and sandstone. It should also be observed that the crushed samples have a somewhat splintery appearance, which is also characteristic of many of the limestone results.

The upper left hand sample, Fig. 1, in which the apex is pointing toward the observer, brings out with remarkable clearness the concentric cleavage structure, illustrated in the granite samples of the previous plate. (Pl. LI.)



Results of crushing limestone cubes.

PLATE LIII.

PLATE LIII.—Results of Crushing Limestone.

The figures in this plate illustrate the results of crushing samples of the strongest limestone of the state. The sample in the lower right hand corner, Fig. 6, gave a crushing strength test of 42,787, lbs. per sq. inch, which is thought to be the highest record obtained for any limestone, dolomite, or marble quarried in the United States. This sample shows, near the apex of the somewhat irregular cone, the concentric cleavage structure, which is typically developed in the granite. (Pl. LI.)

Results of crushing limestone cubes.

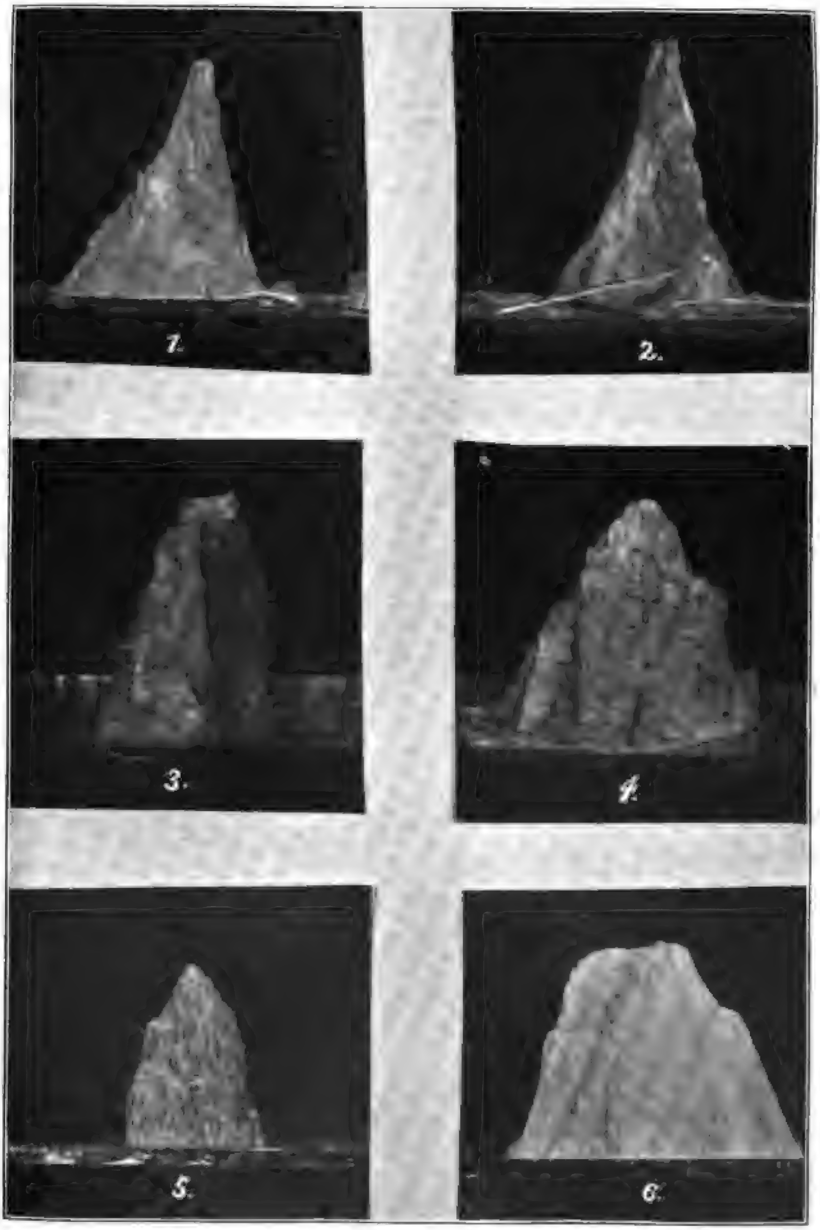
PLATE LIV.

PLATE LIV.—Results of Crushing Limestone, Granite, and Rhyolite.

Figs. 1 and 2.—These figures illustrate nicely the very steep pyramidal or conical forms resulting from crushing limestone.

Figs. 3 and 4.—These are samples of granite and, when compared with figures 1 and 2, they show plainly the difference in the shape of the limestone and granite or rhyolite cones.

Figs. 5 and 6.—The cones shown in these figures are those which resulted from crushing the cubes giving the record tests for rhyolite (Fig. 5) and limestone (Fig. 6). The cones are well proportioned, but the rhyolite is much smaller than the limestone.



Results of crushing limestone and rhyolite cubes.

PLATE LV.

PLATE LV.—Results of Crushing Granite and Rhyolite.

The figures in this plate illustrate some of the more perfect cones resulting from crushing the stronger samples of granite and rhyolite. Fig. 1 is a typical result for granite of this class, while Fig. 3 is a typical rhyolite cone. This latter cone resulted from crushing a two inch cube of granite, which gave a test of nearly 48,000 lbs. per sq. in. It will be further observed that Figs. 4 and 5 have wedge-shaped apices similar to those illustrated in Pl. L., Fig. 3.

Results of crushing granite and rhyolite cubes.

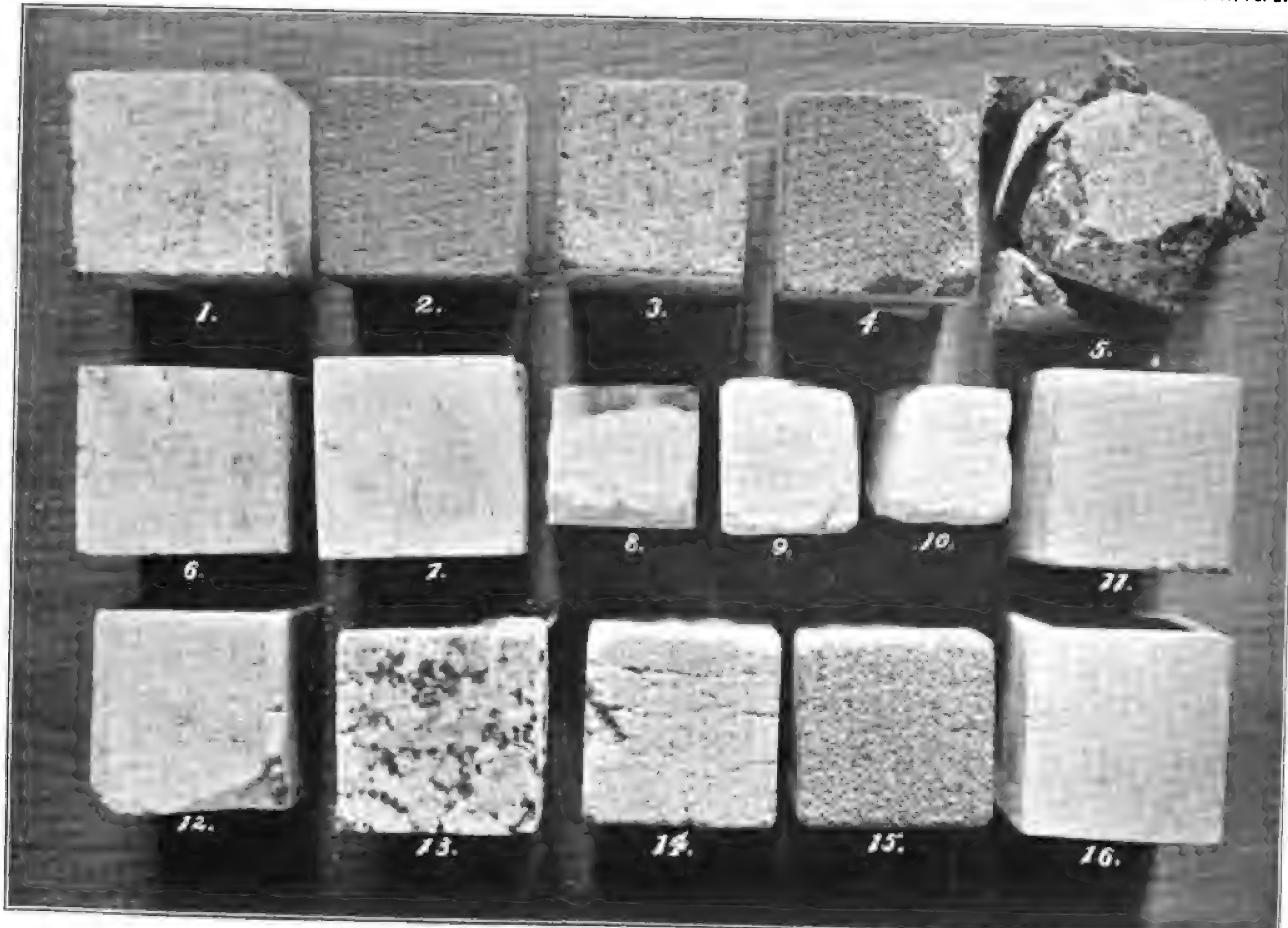
PLATE LVI.

PLATE LVI.—Results of Extreme Temperature on Samples of Granite, Limestone, and Sandstone.

The samples numbered 1, 2, 6, 7, 14, and 16 are granite; those numbered 5, 8, 11, and 12 are limestone; and numbers 3, 4, 9, 10, 13, and 15 are sandstone. Samples numbered 2, 6, and 14, were cooled suddenly by immersing them in cold water, while the remaining were cooled gradually. Number 2 is a fine grained, number 14 a medium grained, and number 6 a coarse grained granite. It is simply necessary to direct attention to these samples, for one to see how the difference in grain influenced the manner of cracking.

The limestone samples were partly calcinated. Where the quicklime has been removed the samples have the rounded edges noticed in numbers 11 and 12.

The sandstone samples are, to all outward appearances, uninjured, as shown in samples numbered 4 and 13. The chipping of the corners and edges in numbers 3, 9, and 10 was occasioned by pressing the thumb against the parts broken off, which in spite of the uninjured appearance of the samples, indicates the friable character of the stone after heating to the extreme temperature of 1300°–1500° F.



Results of subjecting different kinds of stone to high temperatures.

PLATE LVII.

PLATE LVII.—Results of Extreme Temperature on Samples of Granite, Limestone, and Sandstone.

Fig. 1.—A sample of medium grained granite heated to a temperature of from 1300°–1500° F., and suddenly cooled by immersing in cold water. This figure is a good illustration of the result of throwing a stream of water on the walls of a burning building, which is constructed out of granite of this texture.

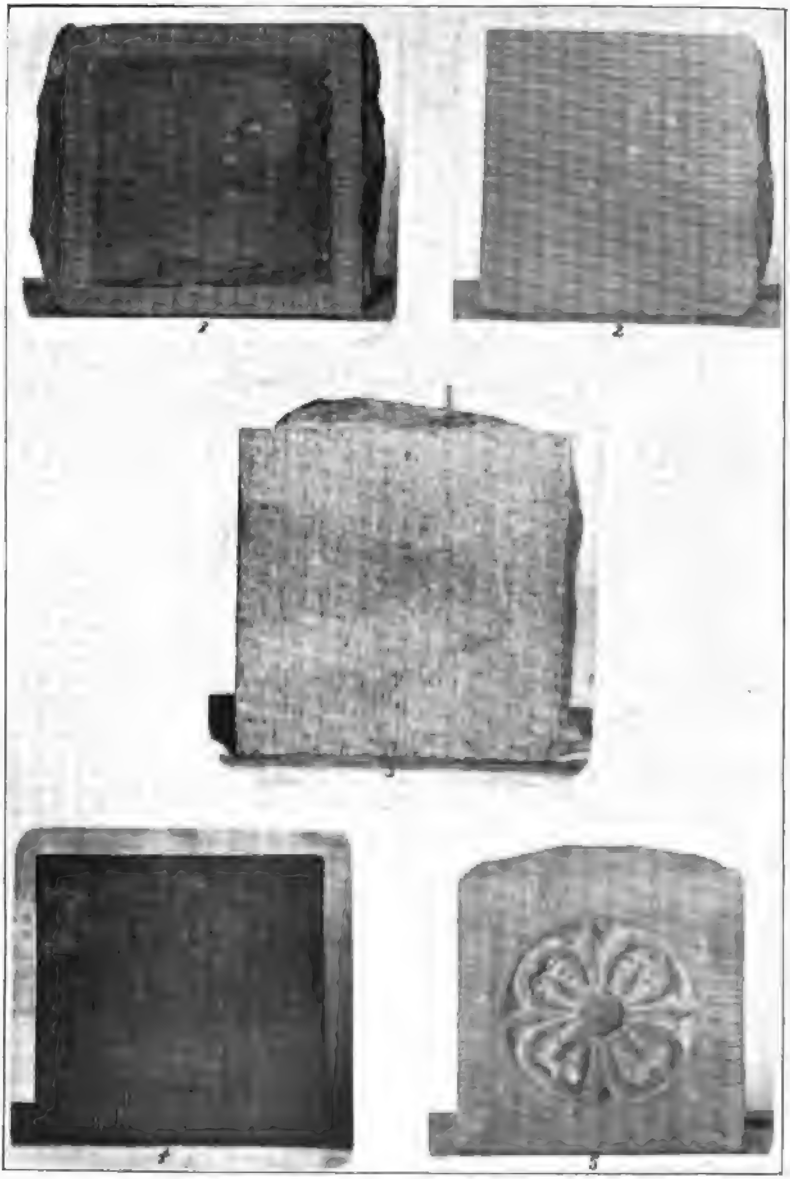
Fig. 2.—The sample in the upper left hand corner is sandstone which has become so friable by being heated to a temperature of 1300°–1500° F., that it crumbles when pressed between the fingers. The remaining samples are limestone. They have flaked off at the corners, due to having been quickly cooled from a very high temperature. Such results may frequently be noticed in the limestone walls of buildings which have been destroyed by fire.

Results of rapidly cooling samples of granite, limestone, and sandstone that have been heated to a high temperature.

PLATE LVIII.

PLATE LVIII.—STYLES OF WORK ON GRANITE AND LAKE SUPERIOR SANDSTONE.

FIG. 1.—Sandstone—Rock face finish.
FIG. 2.—Sandstone—Ribbed.
FIG. 3.—Granite—Bush hammered.
FIG. 4.—Sandstone—Fine pointed surface, with margin.
FIG. 5.—Sandstone—Carved.



STYLES OF WORK.—SANDSTONE AND GRANITE.

PLATE LIX.

PLATE LIX.—Styles of Work on Granite and Limestone.

Figs. 1 and 3.—These figures illustrate very nicely the contrast between the polished and hammered surfaces of the Wausau and Irma granites.

Fig. 2.—This figure is an illustration of what may be accomplished in the way of carving the Duck Creek limestone.

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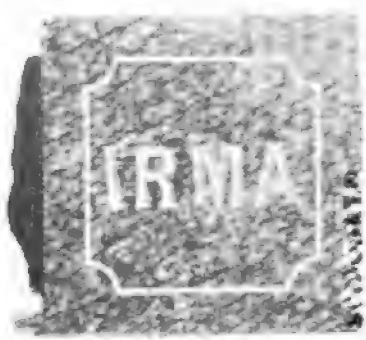

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STYLES OF WORK.—GRANITE AND LIMESTONE.

PLATE LX.

PLATE LX.—MICROPHOTOGRAPHS. (X 12.)*

FIG. 1.—Section No. 4702. Granite from Waupaca. This rock contains a greater variety of minerals than No. 4711. Besides quartz and feldspar there is an abundance of chlorite, epidote, and, in some places, biotite. The individuals are interlocking, but less regular than in many granites.

FIG. 2.—Section No. 4711. Granite from Granite Heights. The dark colored parts are feldspar, and the lighter colored are quartz. This section illustrates nicely the close, interlocking character of the different individuals which contributes largely to the strength of the rock.

*Magnified twelve diameters.

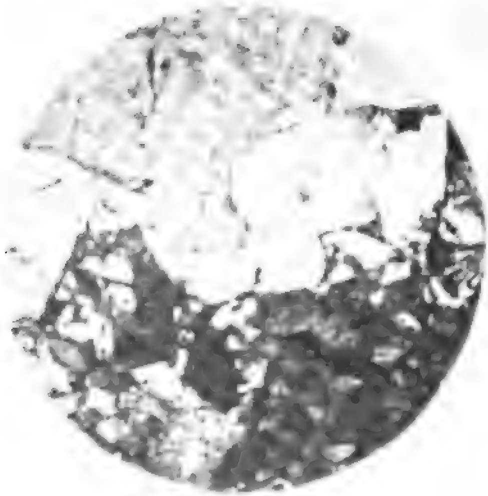
THIN SECTIONS OF GRANITE.

PLATE LXI.

PLATE LXI.—MICROPHOTOGRAPHS. (X 12.)

FIG. 1.—Section No. 4352. Granite from Montello. This section consists mainly of quartz and feldspar, which interlock in a most intricate fashion. This is best shown in the right half of the figure, in which the quartz and feldspar are intergrown. This section illustrates nicely the characteristic of the Montello granite, which gives it the high crushing strength recorded in the table of Physical Tests.

FIG. 2.—Section No. 4706. Waushara granite from near Berlin. The mineralogical composition of this granite is very similar to that of the Montello. The figure shows grains of different sizes, which interlock after the characteristic manner of granite.



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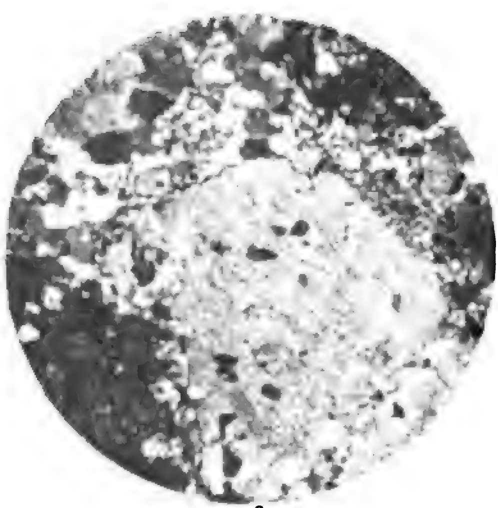

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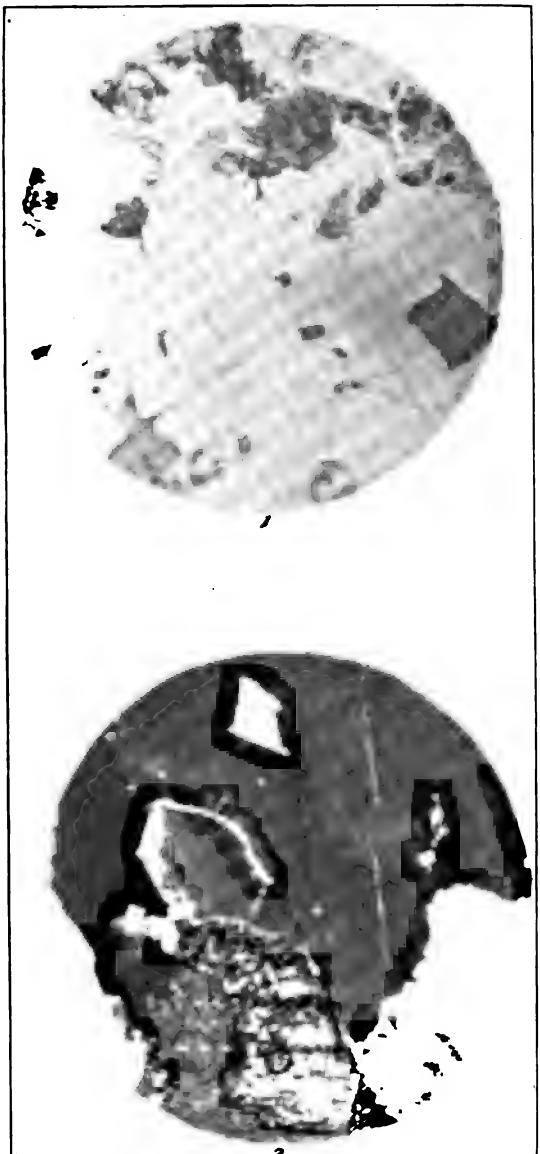
THIN SECTIONS OF GRANITE.

PLATE LXII.

PLATE LXII.—MICROPHOTOGRAPHS. (X 12.)

FIG. 1.—Section No. 4707. Fine grained gray granite from Amberg. This illustration shows mainly quartz and feldspar with two or three small flakes of mica. The interlocking character of the individuals is here again nicely illustrated. Attention is here called to the closeness with which the grains fit into each other, leaving but few interspaces in which water can collect.

FIG. 2.—Section No. 4735. Athelstane granite from Amberg. This figure shows the large size of the quartz and feldspar crystals, and the granulated character of the margins. The individuals are apparently not as intricately interlocking as those in Section 4707, which may be one of the reasons for its somewhat lower crushing strength.



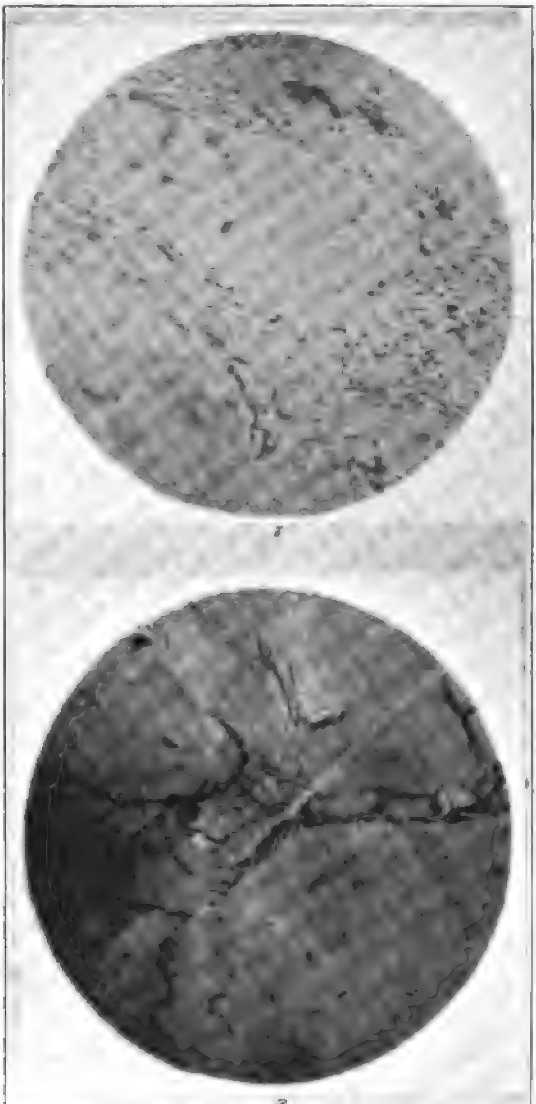
THIN SECTIONS OF GRANITE.

PLATE LXIII.

PLATE LXIII.—MICROPHOTOGRAPHS. (X 12.)

FIG. 1.—Section No. 4733. Berlin rhyolite. This figure shows the exceedingly fine grained matrix and the porphyritic individuals of feldspar, which are characteristic of the rock in the hand specimen. The mica which occurs in small flakes, is also nicely shown. The parallel arrangement of the small flakes, which is evidently a cause for the "rift" in the rock, is well brought out. The cracking of the feldspar, referred to in the text, is also seen in this figure.

FIG. 2.—Section No. 4704. Utley rhyolite. Porphyritic crystals of quartz and feldspar and a small portion of the fine, dense matrix are shown in this figure. The compactness of the rock, with the consequently minute pores and low porosity are very evident.



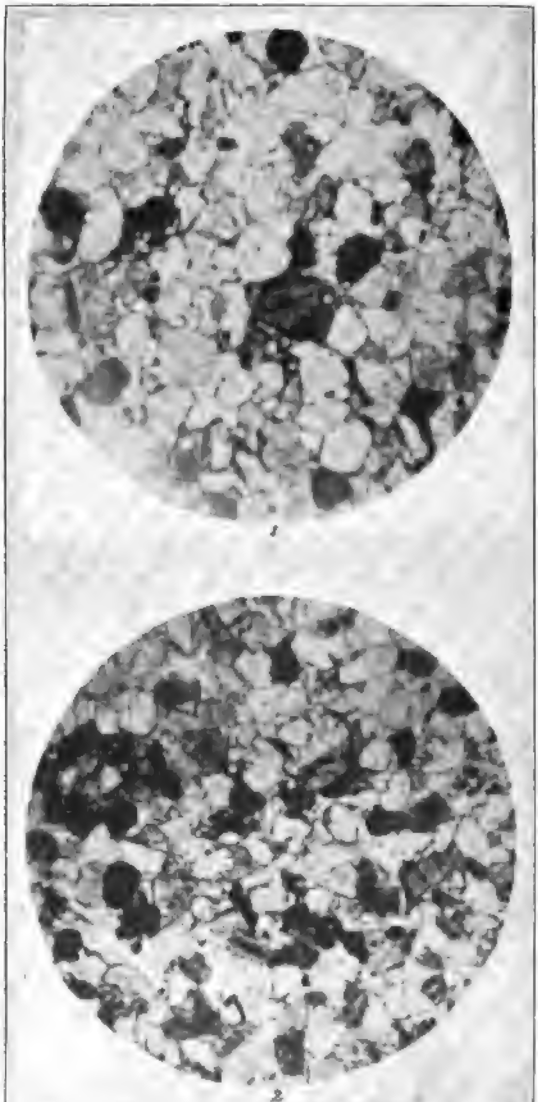
THIN SECTIONS OF RHYOLITE.

PLATE LXIV.

PLATE LXIV.—MICROPHOTOGRAPHS. (X 12.)

No. 1.—Section 4717. Lake Superior brown sandstone from the South Shore Area. This section is composed of uniform, medium sized grains, and has an ordinarily compact structure. These sections should be compared with those of the granite, in order to appreciate the reason for the lower porosity and greater strength of the latter, which depend largely upon the closeness of individuals, and the manner in which they are bound together.

No. 2.—Section 4718. Lake Superior brown sandstone from the South Shore Area. This figure illustrates nicely the round to sub-angular character of the quartz grains. It will be noticed that the grains are closely compacted and that very little clay occurs in the interstices.



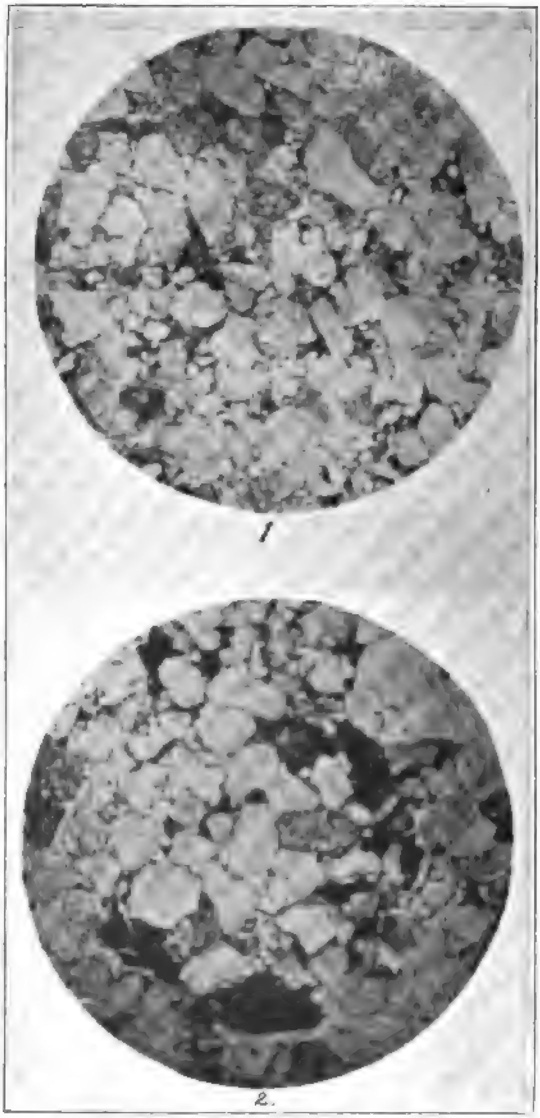
THIN SECTIONS OF SANDSTONE.

PLATE LXV.

PLATE LXV.—MICROPHOTOGRAPHS. (X 12.)

FIG. 1.—Section 4719. Lake Superior brown sandstone from the Chequamegon Area. This section is composed mainly of quartz and the accompanying figure shows the size, shape and arrangement of the grains. It will be observed that they do not interlock, as in the granites illustrated in Pl. LXI., and are not so close fitting.

FIG. 2.—Section 4714. Lake Superior brown sandstone from the Chequamegon Area. The grains are somewhat better rounded in this, than in the preceding section. One will quickly notice the secondary quartz which in many places cements the individual grains together. Occasional grains of feldspar occur among those of quartz.



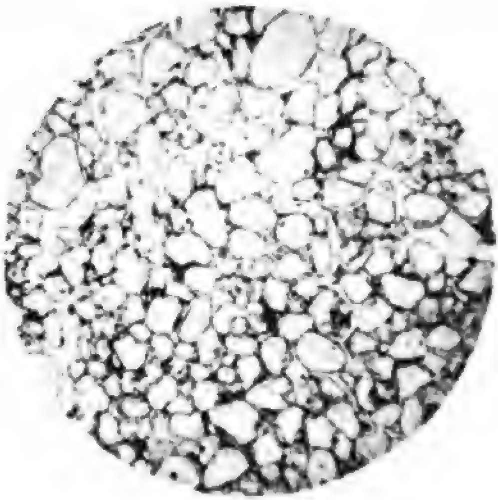
THIN SECTIONS OF SANDSTONE.

PLATE LXVI.

PLATE LXVI.—MICROPHOTOGRAPHS. (X 12.)

FIG. 1.—Section No. 4721. Red sandstone from LaValle. This is an excellent illustration of a sandstone in which the grains were originally uniformly well rounded, and later enlarged and cemented with silica. The enlargements are nicely shown in many places in the section. The brown rims of iron oxide which separate the original grains from the secondary quartz are very distinct in the figure.

FIG. 2. Section No. 4720. Brown sandstone from Argyle. This section illustrates a rock in which the grains are well rounded and cemented with iron oxide, but in which the individuals have not been generally enlarged with secondary quartz. On account of this the stone is considerably weaker than the one from LaValle.



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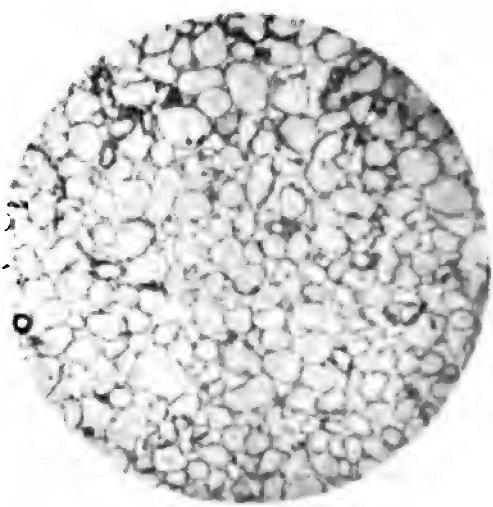

2

THIN SECTIONS OF SANDSTONE.

PLATE LXVII.

PLATE LXVII.—MICROPHOTOGRAPHS. (X 12.)

FIG. 1.—Section No. 4725. Buff sandstone from Dunnville. The fine grained character of this rock and the sharp, angular outlines of the individuals are well illustrated in this figure. The soft character of the rock is shown by the manner in which the section broke in the course of preparation. The composition of this stone is mainly quartz although small flakes of mica occur in some parts of the section.

FIG. 2.—Section No. 4738. White sandstone from Ablemans. This section is mainly quartz, and the individuals, as seen in the figure, are very closely compacted. The outlines are very regular. All these characteristics contribute to the strength of the rock.

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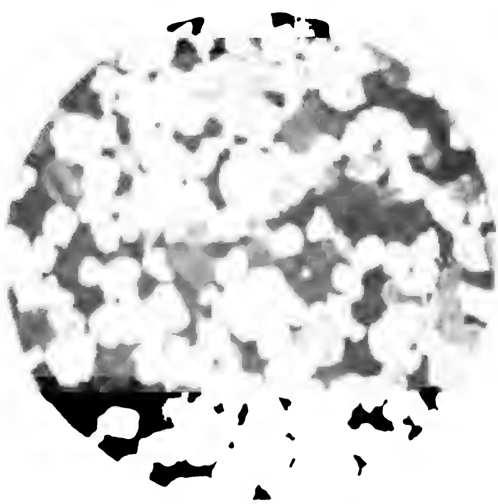

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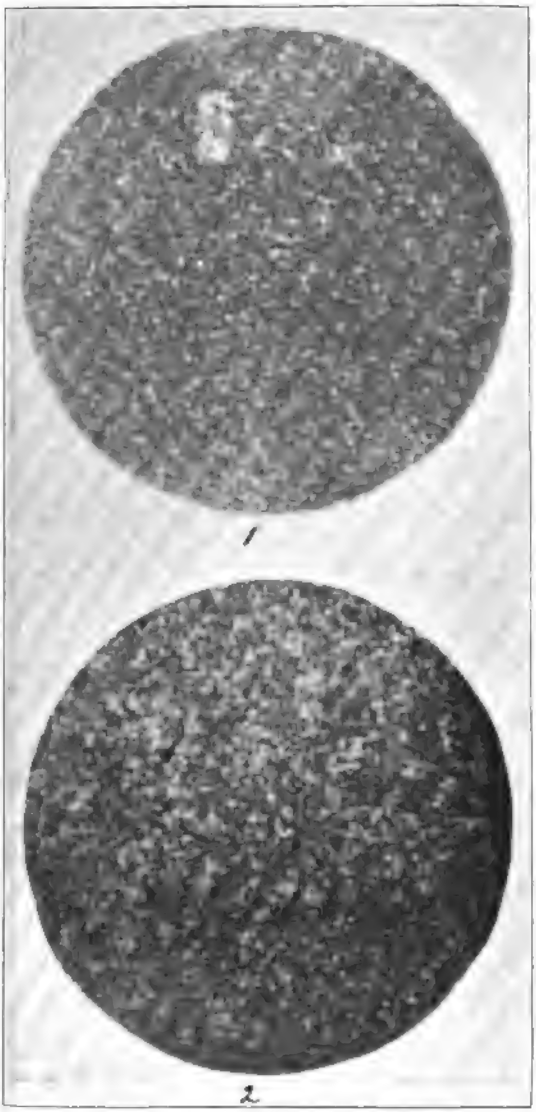
THIN SECTIONS OF SANDSTONE.

PLATE LXVIII.

PLATE LXVIII.—MICROPHOTOGRAPHS. (X 12.)

FIG. 1.—Section No. 4729. Limestone from Genesee. The figure shows that the rock is composed almost entirely of individuals of calcite (and dolomite), which interlock in an intricate manner. The interlocking character and fineness of the grains are both evidence of strength.

FIG. 2.—Section No. 4737. Limestone from Wauwatosa. The section from which the accompanying figure was taken, is composed essentially of calcite and dolomite individuals, in which are embedded several small irregular grains of quartz. Here again, the size of the individuals and their irregular, interlocking margins should be noticed.



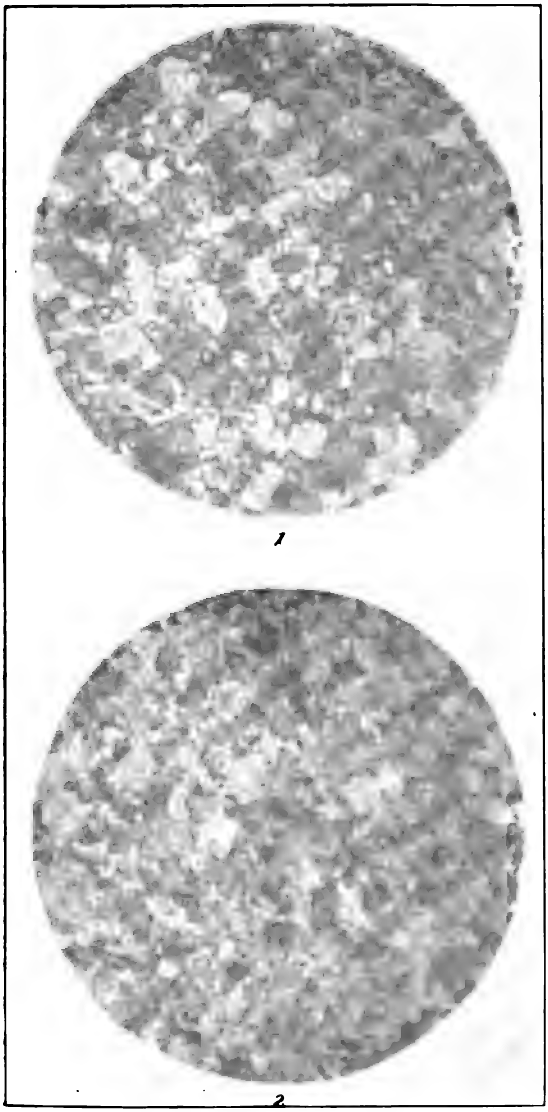
THIN SECTIONS OF LIMESTONE.

PLATE LXIX.

PLATE LXIX.—Microphotographs. (X 12.)

Fig. 1.—Section No. 4736. Dolomitic limestone from Duck Creek. This figure is an excellent illustration of the way in which the individuals of the coarser crystalline limestones interlock.

Fig. 2.—Section No. 4726. Dolomitic limestone from Sturgeon Bay. This figure shows the close, compact character of the crystalline dolomites, which accounts for their low percentage of pore space, and partly for their high crushing strength.



THIN SECTIONS OF LIMESTONE.

INDEX.

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